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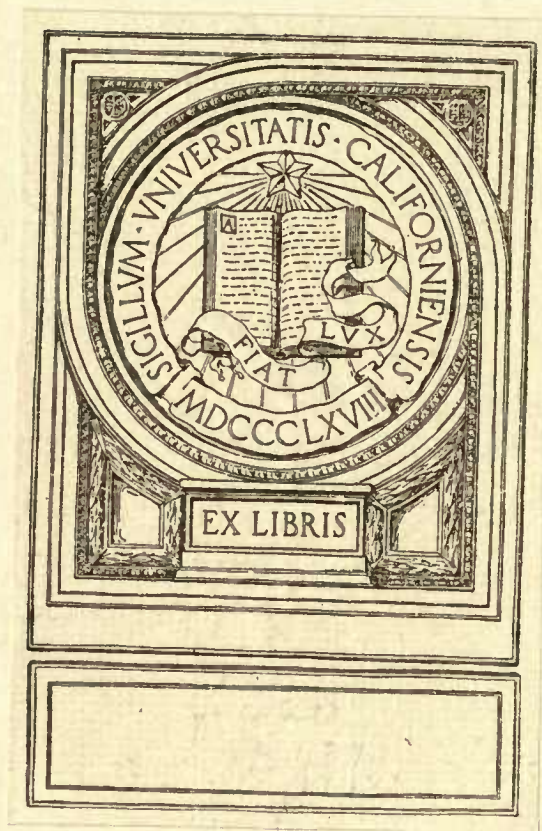
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PUNJAB RIVERS AND WORKS

BELLASIS



PUNJAB RIVERS AND WORKS.

A DESCRIPTION OF
THE SHIFTING RIVERS OF THE PUNJAB PLAINS AND OF WORKS ON THEM,
NAMELY
INUNDATION CANALS, FLOOD EMBANKMENTS
AND
RIVER TRAINING WORKS,
WITH THE PRINCIPLES FOR DESIGNING AND WORKING THEM.

BY
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AUTHOR OF "HYDRAULICS WITH WORKING TABLES,"
AND "THE SUCTION CAUSED BY SHIPS."

SECOND EDITION,

REVISED AND ENLARGED.

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PREFACE TO SECOND EDITION.

Of the many interesting problems which present themselves to the Irrigation Engineer in India, not a few arise in connection with the Inundation Canals of the Punjab and the Flood Embankments which form part of the Canal systems. General rules and principles for dealing with these Canals and Embankments have gradually been evolved, but there has hitherto been no treatise setting them forth or giving detailed information concerning the works.

The Training of the Indus, in the District of Dera Ghazi Khan, constitutes another series of problems which has, of recent years, been a great deal before the public but hitherto there has been no complete and succinct account of it. The subject is akin to that of the Canals and Embankments (in both cases a knowledge of the character of the shifting Punjab rivers is the first thing required) and the work is generally supervised by the same Engineers.

The need for information on the above subjects gave rise to the preparation of the present work. The book is based on personal experience extending over a great number of years. The references to "Hydraulics" are to the Author's work on that subject.

The book having met with a favourable reception, not only from the Indian Engineers for whom it was chiefly intended, but from English and (especially) American Engineers, the first edition has been exhausted. The new edition has been carefully revised and some matter added. It is hoped that it will be of use to anyone who has to deal with rivers or streams in alluvial soil.

E. S. B.

CHELTENHAM :

15th July, 1912.

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ABBREVIATIONS.

H. F. L. stands for High Flood Level.

F. S. L. stands for Full Supply Level.

R. L. stands for Reduced Level.

R. D. stands for Reduced Distance or Chainage.

ERRATUM.

Page 32, line 11 from bottom, for “where it” read “which.”

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PUNJAB RIVERS AND WORKS.

CHAPTER I.

THE RIVERS, WITH BRIEF DESCRIPTION OF WORKS.

SECTION I.—DESCRIPTION OF THE RIVERS.

Art. 1.—*General Description.* Although the Punjab takes its name ⁽¹⁾ from the rivers, Jhelum, Chenab, Sutlej, Beas and Ravi, yet its largest river, by far, is the Indus ⁽²⁾. The other five rivers all unite and fall into the Indus just before it leaves the Punjab. Fig. 1 shows, on the scale of 4 miles to an inch, a plan of a portion of the Indus, above the junction, at low water. If the scale be supposed to be enlarged several times, the plan will represent, pretty fairly, a portion of any of the other rivers ⁽³⁾. The rivers are all similar in character. The stream is always tortuous and crosses over from side to side of its channel, a large portion of which is occupied by sand-banks and minor arms or “creeks.” The width of the river bed is, on the Indus, generally about four miles, on the Ravi, which is the smallest of the rivers, less than half a mile. The river valley generally consists of a wide and very flat tract of country. It has a slope, in a direction parallel to the river, about equal to that of the river itself. The banks of the river are about the same height as the flood level of the water, but they may be for long lengths above flood level and for other lengths below it ⁽⁴⁾ and the country subject to periodical floods. Very commonly, owing to the land nearest the river having received successive deposits of silt, the country falls, in going away from the river, perhaps for several miles and then rises again.

Art. 2.—*Rises and Falls.* The rivers derive their supplies largely from the melted snows of the Himalayas, and the volume of water is, roughly speaking, proportional to the temperature. In the winter, that is from 1st November to 1st March, the water level is almost stationary, and the depth of the water may be 8 or 10 feet. In March the rivers begin to rise, attain their greatest height in July and August, and fall rapidly in September and October. From June to September the supplies are greatly augmented by the heavy rains which fall in and near the hills. The rain causes the water level to fluctuate greatly. On the Indus the highest flood of the year is commonly about 8 feet, and sometimes 10 or 12 feet, above the winter level of the river. On the other rivers the range may be greater ⁽⁵⁾. On the Indus the highest floods are generally over by the

(1) Punjab means “five waters.”

(2) The old “Punjab” did not include the country west of the Indus.

(3) This plan and description do not apply to the short sub-montane reaches of the rivers (where the beds are of boulders or shingle and the great Perennial Canals generally take off), but to the rivers as they pass through the great alluvial plains where the Inundation Canals and other works described in this book are all situated.

(4) On the Sutlej the country is generally above flood level.

(5) On the Chenab the range is 13 to 15 feet and the floods are often sudden.

10th or 12th August (1). On the other rivers they are generally over by the 20th August, but sometimes a heavy flood comes in September.

Winter rain also causes, on all the rivers, temporary rises ranging, usually, from 1 to 3 feet. These rises occur sometimes in December, but more commonly in January, February or March.

Art. 3.—*Discharge, Depth, Velocity, Gradient, etc.* The discharge of the Indus in the winter is about 22,000 cubic feet per second. In a high flood it is perhaps fifteen times as great. The discharges of the other rivers are all much less than that of the Indus. The depth of water in a high flood in the Indus, in the deepest part of the stream, is 20 to 40 feet, but it may be 50 feet in a bend near the concave bank. The velocity of the current in winter, in any of the rivers, is generally less than 4 feet per second, but in high floods it may be 6 or 8 feet. The surface gradient averages somewhat less than a foot per mile, but it varies from reach to reach. Sometimes the stream is abnormally narrow and this causes a steep gradient in the reach concerned and a flat gradient upstream of it. Generally, the surface of the water is smooth, but occasionally there are large waves, dangerous to small boats, especially where the depth is small and the current rapid.

Art. 4.—*Shifting nature of the Rivers.* The velocity of the main stream is generally too great for the channel and in consequence scour is constantly occurring. The water being thus highly charged with silt, deposits occur in other places. The proportion of silt in the water is greatest in the main stream, especially where bank erosion is going on, and less in creeks. The whole river is in a continual state of change. The whole arrangement and appearance of the channel at the end of the flood season is usually quite different from what it was at the beginning. The main stream has two methods of altering its course. The first consists in a gradual shifting of its position, one bank being eroded while silt is deposited at the other. This kind of change is generally termed "Erosion." It generally takes place where the channel, or at least the eroded bank, is more or less curved. It may be slow or rapid. Sometimes the eroding edge of the stream shifts laterally fifty or a hundred feet in a day. The second kind of change consists in the scouring out of a new channel or the enlargement of a small one, generally across a sand-bank or down a creek. Such a change is known as an "Avulsion." It takes place chiefly during the high floods and the abandoned channel probably becomes a creek.

The changes in the river occur with such irregularity that it is impossible to forecast them. They are, no doubt, governed by laws, and if the surrounding conditions, such as the nature and height of the banks and the quantity of water in the river, were always the same, the laws might be apparent; but as it is, they are not. Erosion of the bank can be predicted when the stream is much curved, but not with certainty and the amount of the erosion never.

(1) They are nearly always over by the 15th August. In the year 1878 it seems to have been assumed that this would, as usual, be the case and vigilance was perhaps relaxed. The river remained high for a week or two longer, a breach occurred in a Flood Embankment and the cantonment of Dera Ghazi Khan was submerged, most of the buildings which were of sun-dried brick, falling down or being badly damaged.

The river may, during floods, silt or scour for a considerable length, or it may become wider or narrower. Whether it tends to silt and contract in a year of low floods and to deepen and widen in heavy floods is not known. A change of any kind is probably more or less local and temporary and dependent on the local or temporary flood conditions. It is not known that the rivers have any general tendency to change of any one kind.

Art. 5.—*Erosion*. Erosion of the banks is of daily occurrence. It affects not only the sand-banks but also the banks proper or boundaries of the channel. It may continue in one locality for many months and hundreds of acres of land, including fields and villages, may be cut away and wholly disappear, the erosion progressing in the manner shown by the dotted lines on Fig. 1 (1). It may become localised at one point or another. It may cease abruptly or it may continue until the stream deserts the channel and adopts a straight course across the bend. By this time the edge of the stream may, at least on the Indus, have moved a mile or more from where it was before. There may be a period of cessation of erosion, but as long as the stream remains where it was, the erosion may at any time, except in the lowest stages of the river, recommence. When erosion is in progress the bank above the water level becomes vertical. The bank below water has a steep slope, and as this slope is cut away by the current the bank above water cracks and large pieces then come away and fall into the water with sounds like those of distant guns. A falling piece may weigh several tons and a small boat cannot approach the bank without danger of destruction.

Erosion almost ceases when the river is at its lowest, and it is said that it does not go on to any great extent when the river is at its highest, but when the river is at its highest the country is often flooded so that any erosion which then occurs is invisible and noiseless. It is now well understood that the tendency of a stream to scour or transport silt increases with the velocity, but decreases with the depth (Hydraulics, Chap. VI., Art. 14). Velocity increases with depth in such a way that the actual scouring power may or may not increase with depth. On the Punjab rivers scouring power seems to be greatest at intermediate stages of the river. It is sometimes said to be specially great when the river is falling, and that this is because the soil is then soaked with water which drains off, leaving hollows. This, however, could only account for a trifling and temporary falling in of the banks. The real cause of the falling in is the scouring away of the sloping part below water. Such scour seems rather more likely to occur with a rising river (Hydraulics, Chap. IX., Art. 5), than with a falling river.

While erosion is going on in any reach along, say, the right bank of the stream, then the right hand portion of the stream in that reach, and also for some distance downstream of it, carries an unusually high charge of silt. This is crudely expressed by saying that the stream is dissolving and carrying away all the masses of bank which falls into it. There is no proof that such masses dissolve at once. The real fact is that the erosion is due to the high velocity along the right bank, and this high velocity is of course accompanied by a high silt charge, some of the

(1) The curve of the bank is not often a circular one but tends to be sharp at one or more points, especially towards the middle of the curve (Hydraulics, Chap. VII., Art. 1).

silt coming in from upstream and some being scoured from the slopes and bed of the reach.

Art. 6.—*Avulsions*. Avulsions, though they usually occur within the river channel, have been known to occur across country, but only under circumstances very favourable to their occurrence, *e.g.*, where the channel is curved and the new channel follows the chord. The Beas now joins the Sutlej scores of miles above the ancient junction and the old dry channel of the Beas between the new and the old junction still exists. The change may have been by avulsion but it was probably by erosion, the Beas gradually shifting its position till it effected a new junction with the Sutlej. It is common to hear dread expressed of a river taking a new course into some low land, *e.g.*, the Jalpa depression in Dera Ghazi Khan or the Kirn depression in Gurdaspur. Such fears are nearly always groundless. Moreover, such changes can be prevented by simple Embankments (Art. 13).

Art. 7.—*Changes in the Creeks*. In a creek changes go on in the same way as in the main stream. The velocity of the current in a creek being less than in the main stream, a deposit of silt generally takes place in the former, especially in its upper reaches, and in most cases it eventually becomes silted up altogether unless the main stream either swallows it up by erosion of the intervening land or enlarges it by avulsion. A creek, however, may last for many years and even become permanent.

Art. 8.—*Changes in the Water Level*. The water level at any point in the river channel depends of course not only on the quantity of water in the river but also on the cross-section of the channel. Any enlargement, if extending over a long length of channel, causes a fall in the water level in the enlarged length and for some distance upstream of it. A contraction causes a rise upstream.

The water level also depends on the course of a stream. Suppose the surface gradient to be a foot per mile and the course to alter from that shown by the firm lines in Fig. 2, to that shown by the dotted line, the water level at *b* will be a foot higher than before, although the general level of the stream *ac* is supposed to be unaltered. A change in the water level at any point may also be caused, to a slight extent, by changes in the set of the current (Hydraulics, Chap. VII., Art. 1).

Again, the water level in a creek is generally different from that in the main stream opposite to it. If the water levels at two points, one in the river and one in a creek, are equal, to begin with, the silting up of the head of the creek, which almost invariably occurs, will soon cause the water level in the creek to be lower than that in the main stream. A difference of two feet is nothing uncommon. This, in a great measure, explains why a portion of land which is flooded one year may escape flooding in another year, although there may be just as much water in the river as before. When the main stream is near to, say, the west bank, the floods on the west bank are likely to be most severe. The natives crudely say that this is due to the "set of the stream." It is really due to the cause just stated.

It will be readily seen that the probable flood levels along either of the banks of a Punjab river cannot be foretold with accuracy or obtained by simple proportion.

The changes in the water levels of course give rise to changes in the surface gradients.

Art 9.—*Changes in the Sand-banks.* Newly-formed sand-banks, excepting any parts which are again eroded by the stream, keep receiving fresh deposits and are built up to about flood level. The portions near the main stream are generally the highest. The upper layers are generally of clay. The newly-formed land, whether it is an island or is attached to the river bank, generally becomes rapidly covered with jungle or is brought under cultivation. In this way the river supplies fresh land in place of what it cuts away at other places. Such lands, though they have been formed by deposits from the stream and are therefore obviously not above what was once the flood level, are not always submerged in floods. This may be due either to the general height of the flood being less than before or to the local height being less for the reasons explained in the preceding article.

SECTION II.—PERSISTENT SHIFTING OF RIVER IN ONE DIRECTION.

Art. 10.—*Westward tendency of the Indus near Dera Ghazi Khan.* In a reach, some 70 miles in length, near the South of the Punjab, and not far from where the river enters Sind, the Indus, in its changes, attacks the right bank more than the left and thus the net result, at the end of a series of years, is generally a westward movement of the main stream and of the river bed. In the 35 years from 1875 to 1910 the westward movement has amounted in places to 2 or 3 miles.*

In the reach in question the country on both banks is generally below flood level, and there are on both banks long flood embankments. The westward movement not only threatened to destroy the town of Dera Ghazi Khan but it destroyed, in many places, the flood embankments which had to be reconstructed further away from the river and in lower ground, the cost being thus greatly enhanced and the danger of breaches increased.

Art 11.—*Speculations as to its causes.* The causes of the westward movement are not known. Fig. 3 shows that it is not due to any general curvature of the course of the river. The movement seems to have been chiefly confined to the 70-mile reach. It has been suggested that it is due to the rotation of the earth. Taking the average southerly velocity of the stream to be 4 feet per second, the distance traversed in an hour is 2·4 miles, which represents, in the latitude in question, a difference in the velocity about the axis of the earth, of ·44 feet per second. This difference takes place in an hour and the pressure on the western bank due to it must be exceedingly small. Though eternal in its operation it could produce little effect. Moreover, a similar force operates in numerous other reaches in the Punjab where the river flows from north to south, but there is no westward tendency in them.

* The westward or other movement of the river can best be seen by considering the position of the centre of the main stream. The main stream and creeks are surveyed every year and shown on maps. The "high bank" or edge of the river channel is not always surveyed, and it is often indefinable because the neighbouring sand-banks have silted up to the level of the country and have been ploughed by the natives and become indistinguishable from the neighbouring fields. When the river divides into two branches of about equal size, both are considered to be main streams.

The draw of the canals is wholly insufficient to account for the western movement. The discharge of a single canal is never more than 1 per cent, nor the united discharges of all the western canals more than 4 per cent, of the discharge of the river. Moreover, the eastern canals are larger than the western. There was lately a proposal to enlarge one of the western canals, close to the town of Dera Ghazi Khan, so that it would carry, in floods, about 2,000 cubic feet per second. Fears were expressed (not by professional engineers) that the river might be drawn towards the town, or that, at least, if the river did come nearer to the town, the change would be attributed to the enlargement of the canal. The latter of these contentions may have had some force, the former none. The canal was to have had a flat slope, and even when enlarged would have silted and not scoured.

The whole river, in its passage through the Punjab, is said to have once flowed many miles to the east of its present course. It is said to have then moved slowly westward. About the year 1400 A.D. the river, both in the 70-mile reach and for some miles north of it and south of it, undoubtedly flowed some 6 or 8 miles to the west of its present course. Its western bank is still traceable. When Dera Ghazi Khan was founded, 400 years ago, the river was moving eastward.* The recent and present (for it still continues) westward tendency seems to be merely one of a series of great and slow changes which can no more be explained than the local and rapid changes already described †

SECTION III.—WORKS UNDERTAKEN IN CONNECTION WITH THE RIVERS.

Art 12.—*General Description.* The works undertaken in connection with the rivers and described in this book are Irrigation Canals, Flood Embankments and River Training Works. Each of these is described separately in Chapters II to IV. (Chapter V dealing with the annually recurring work on all the above and the procedure adopted for accomplishing it), but as they are more or less connected with one another a brief preliminary description of them all will facilitate matters.

* See also Chap. IV, Art 9.

† The soil on the eastern bank of the Indus in the 70-mile reach is similar to that on the west, but the eastern bank is in many places fringed with forests consisting mostly of rather small trees. The roots of the trees undoubtedly offer some resistance to erosion. On the Ravi just above the head of the Sidhnai Canal there is a perfectly straight reach about 6 miles long. No straight reach of anything like this length exists on any other river in the Punjab plains, nor any reach, straight or crooked, of anything like so permanent a character. There is a tradition that the straight reach was artificially made and that trees were planted along its edges. However this may be, good-sized trees exist along both edges of the stream and their roots must prevent erosion. The forests on the east of the Indus must have a tendency to prevent the stream from moving to the east. The stream must, like all other streams whose velocity is too great for its bed, make itself crooked in order that the slope may be flattened and the velocity reduced. In certain reaches (Fig. 36) it happens to become fairly straight and it must then assume large bends in other reaches. Unable to form the bends by cutting to the east it cuts to the west. The idea that the river must have "room in which to move about" is nothing new. It is true that the resistance to eastern erosion exists only when the stream is actually touching the eastern side of the channel where the forests are (very often it does not touch it for many miles) but these occasions may be sufficient to give it a westerly tendency. The vast changes which occur every year show that a small thing can bring about a great result. The above may possibly be one cause of the westerly tendency.

The Canals are generally called "Inundation Canals" because they usually flow only in summer when the rivers are high. They have no headworks and no weirs across the rivers. Owing to the changes in the river the off-takes of the canals have often to be changed and fresh channels dug or creeks cleared out. The supplies of the canals are not always what is desired.

In most of the districts in which Inundation Canals exist the rainfall is very scanty, and the crops chiefly depend for water on canals, river inundations and wells. In order that the water of a canal may be made to flow on to the surface of the country, the canal must generally have a direction making an acute angle with that of the river and a general slope flatter than that of the river, but when the country falls away from the river, a canal may start at right angles to the river. Sometimes a canal, after crossing the river valley, runs nearly parallel to the river along the slope of the watershed and irrigates land many feet higher than the flood level at a point immediately opposite. The bed of a canal is below the surface of the ground, but the water level generally above it, and the irrigation is by "flow." The land near the head of a canal is generally too high to receive flow irrigation except in floods. It may be irrigated by "lift" either from the canal or from the river; owing to the smaller lift this is much easier than irrigating from wells, and the water contains fertilizing silt. Land irrigated by canals obtains two crops, the *Kharif* or summer crop and the *Rabi* or winter crop. The land for the latter is soaked with water in August or September and afterwards ploughed. The crop is sown in November and December, and is generally matured by water raised from wells.⁽¹⁾ The principal summer crops are rice, indigo, cotton and millet, but the largest crop of all is the winter crop of wheat and barley. The Inundation Canals of the Punjab irrigate yearly about 1¼ millions of acres. They are upwards of fifty in number.

River inundations are apt to be uncertain and they are of use only for the winter crop. The summer crop, if sown, would be damaged or destroyed by the floods. The winter crop is sown on the soaked ground, as in the case of canals, and matured from wells.⁽²⁾ Moreover, the river inundations benefit the soil only in a belt near the river where silt is deposited. Beyond that the flood water does harm to the soil. In order to convert a flooded area into a canal-irrigated area Flood Embankments are made. They run generally parallel to the river and the canals pass through them by means of masonry regulators. Flood embankments have to be set back some distance from the river in order to be fairly safe from erosion. The flood embankments on the Punjab rivers aggregate some 400 miles in length.

When the river is in flood the safety of the embankments is very important, and large numbers of men are employed in patrolling them day and night, so that any leak may immediately be discovered and stopped; otherwise it may rapidly become an open breach, and the floods burst into the country, doing enormous damage to crops, and laying waste many square miles of country. Sometimes the river in eroding its bank cuts through an embankment. If this occurs during the flood season, it is

(1) On land very near the river the use of the wells is often dispensed with.

(2) Do. Do. Do. Do. Do.

necessary to rapidly construct a new embankment in rear of the first. This is often a work of great difficulty owing to the scarcity of labour in the summer. This again is largely due to the fact that the people, notoriously improvident, have just then enough food grain for their immediate needs.

Although the trouble and expense caused by the changes in the rivers are so great, works for controlling or training the rivers are never undertaken merely for the sake of protecting a canal head or an embankment. The cost and uncertainty would be far too great.

River Training Works have been carried out extensively on the Indus, but their object has in every case been to check the westerly movement of the stream. The works have been local (the chief work was a Stone Embankment) or scattered (Groynes) according as the object has been to protect the town of Dera Ghazi Khan or to protect the flood embankments and the country generally. The local works have been generally carried out by the Buildings and Roads Department of the Punjab Government, the Groynes by the Irrigation Department.

The soil in the tracts traversed by the canals and embankments is very often light and sandy. It is also often impregnated with salts. Good earthwork is often difficult.

There are, at frequent points in the canals and at a few in the rivers, fixed gauges to show the rise and fall of the water. They are read daily and registered. Owing to the causes described in Art. 8 and to the deposit of silt in the canal head reaches, the rises and falls on different gauges, e.g., in a canal and in the river, do not always agree.

The canals, embankments and groynes which lie in one district or which form any convenient group, constitute a "Division" which is in charge of an Executive Engineer. A division has two or more "sub-divisions" each under a Subdivisional Officer, who again has several Overseers or Sub-Overseers each in charge of a section. Many of the canals are now in process of being remodelled and improved, and the amount of work to be done is double what it used to be when they had merely to be maintained and worked.

All these works, although they may not hold the first place as producers of revenue, are of supreme importance as regards the welfare and contentment of the people concerned. They constantly present new problems and offer plenty of scope for originality.

Art 13.—*Popular Confusion as to Training Works and Embankments.* In discussions in the newspapers, in connection, for instance, with the town of Dera Ghazi Khan, there is often complete confusion between floods and shifting of the stream, between embankments and training works. A flood spilling over a country may do damage and even cause houses, if their foundations are bad, to fall down. It can be stopped by simple embankments of earth. Erosion may be almost impossible to stop and it may wholly remove a house or town together with the ground on which it stood. If the erosion does not reach the town but removes a flood embankment, it may allow water to enter the town, but this will be simple flooding. One reason why confusion exists between the danger of flooding and the danger of erosion is probably that flooding is popularly connected with avulsions which, as already stated, are of the rarest occurrence except within the bed of the river.

CHAPTER II.

INUNDATION CANALS.

[For preliminary information see Chapter I, Art 12.]

SECTION I.—DESCRIPTION OF THE CANALS.*

Art 1.—*General Description.* The canals differ greatly in size, the head widths varying from 10 to 100 feet and the lengths from 8 to 60 miles. The bed level at the head is generally about the same as the winter sub-soil water level, and this is about the same as the low water level of the river. The depth of water in the canal at any time is thus about the same as the height of the river above its low water level. In most canals it averages about 5 feet, but it may sometimes be 10 feet. A large canal usually gives off branches or distributaries. These again give off water-courses which, on a large canal, may number hundreds. They are maintained by the people and not by Government. The bed slope of a canal is seldom steeper than 1 in 4,000 or flatter than 1 in 10,000. The side-slopes generally become, by silting, about half to one. The canals† were in most cases dug originally by the natives and are crooked. The widths are also somewhat irregular.

The banks of the canals are often somewhat weak and liable to breach. In such cases the banks are patrolled and watched. Breaches, except those near the heads (Art 6) can generally be closed in a few hours. The flow through the breach is generally stopped by rough stakes and brushwood, or in bad cases by sand-bags. Earth is then rapidly added.

The strengthening of canal banks where liable to breaches is a work which should constantly be seen to. The amount of attention which it receives is generally altogether insufficient. In the winter all hands are busy with other work, but the necessary cross-sections for bank strengthening can be taken while the canals are flowing and so much of the earth-work can also be done then as is to be taken from borrow-pits outside the canal.

A canal generally has a masonry flood regulator, a few miles from the off-take, to enable excessive supplies to be shut off. The regulator cannot be placed near the off-take because this is often changed and there would also be fear of its destruction by erosion of the river bank. At the flood regulator there is generally the off-take of an escape leading back to the river and there is often also the off-take of a branch or distributary.

If the canal crosses a flood embankment the flood regulator is at the point of crossing. Further down the canal there are other regulators, generally at the off-takes of branches or distributaries, but sometimes at other places in order to head up the water during low supplies.

* The present description consists chiefly of matters peculiar to Inundation Canals. For general descriptions of Irrigation Works reference may be made to books on that subject. Inundation Canals are similar to Perennial Canals in most respects. They are aligned, designed and worked on similar principles.

† Unless there is something repugnant in the context "canals" include canals, branches and distributaries, *i.e.*, all the Government channels.

The Head Reach (often called, for shortness, the "head," while the actual point where the canal begins is called the "off-take") is the uppermost five miles or so of the canal, and this often corresponds roughly with the reach upstream of the flood regulator.

The banks of the canals generally have trees and jungle growing on them. Fresh trees are also planted in lines on the banks and slopes, but not generally near the channel because they are somewhat apt to fall into it.

A canal generally has a bridle road, and often a proper road fit for wheeled traffic, but not metalled, along one or both banks. The road on one bank is called the "Inspection Road" and is reserved for the use of officials⁽¹⁾. The other bank is open to the public. Where watercourses take off, rough bridges made of branches of trees, grass, and earth, are thrown across them.

For the purpose of fixing the dates of opening the canals they are divided into three classes: An "Ordinary" canal is opened about the 6th May. An "Early" canal is one which serves a tract of country where certain crops, which require early watering, are grown in sufficient quantities to render an early opening necessary. Such a canal is opened about the 26th April. A "Late" canal is one where there are no considerable areas requiring water till about the 15th May or (sometimes) 1st June. All the above dates are averages and approximations. The actual dates depend upon the demand for water, the height to which the river has risen, the tendency of silt to deposit in the canal and the probability of damage occurring from breaches. (For further details see Appendix A.)

The canals generally go dry about the 30th September and thus the period of flow is generally about five months.

Art 2.—*Silt Deposit.* The velocity in a canal being less than that in the river a deposit of silt generally takes place in the canal. The silt consists of sand and clay. The sand, with a little clay, is deposited in the head reach of the canal. At the close of the irrigating season the deposit at the off-take is generally from 1 to 3 feet deep and it extends downstream, gradually decreasing in depth, for a distance which may be less than a mile or may be 6 miles. The deposit is generally greatest when the canal takes off from the main stream, especially if erosion of the bank from which the canal takes off, is going on, and least when it takes off from a creek. There may be some deposit, probably clay, near the tail of the canal.

There is generally no deposit in the middle portion. There is nearly always a silt bank at the inside of a bend, but there is a corresponding hollow at the outside, so that the general level of the bed is about the same as it is just above or below the bend. Large sums of money have been wasted by removing the silt banks which are known as "side-silt." Their removal makes the cross-section greater than elsewhere, and they quickly form again (Hydraulics, Chap. VII, Art. 1, foot of page 224).

(1) Otherwise it would soon be cut up. Europeans cannot be out in the sun all day. Anything which facilitates their touring about and seeing things for themselves is in every way to be encouraged.

The silt when removed from the canal is generally placed equally on both sides behind the banks and levelled down to the same height as the banks. Much silt is deposited in the water-courses. It is cleared out frequently by the people.

The deposit of silt in the head reach of a canal is the greatest evil with which the canal Engineer has to deal. Deposit in reaches further down the canal, if it occurs, is not nearly of so much consequence. In many cases a "subsidiary head" is provided and kept closed, and therefore free from silt, till the time when the floods are falling. Deposit in the head reach not only reduces the supply below the demand, except in high floods, but it cuts off the supply when the river finally falls and causes damage to, or failure of, standing crops.

In the reaches downstream of the head reach the heading up of the supply by regulators, provided it is intermittent (say, 3 to 5 days a week), generally causes little deposit and often does not cause much deposit even if continuous. Also an unduly large cross-section or a succession of sharp bends may cause little or no deposit. But in the head reach matters are quite different. The steps to be taken in this connection are described in Section II.

The deposit of silt in branches and distributaries is generally similar to the deposit in the main canal being generally greatest near the head and absent in the middle.

While the canals are flowing certain small obstructions occur owing to trees, branches, etc., falling into the channels, or coming in from the river or to temporary bridges, etc., partly falling down. These obstructions often cause "snags" and irregular silt-heaps, generally of small dimensions. In reaches (there are many such) where the bed of the channel is lower than it is intended to be, such obstructions, etc., should not be removed unless the eddies or rush of water caused by them are such as to damage the banks.

Art 3.—*Erosion of Banks.* Erosion of banks may occur, especially in large canals and at bends. It is likely to be very serious in sandy soil, and this is most common in the head reaches (Art 12). The best and most common method of stopping it is "Bushing." The object is to cause a berm to be formed. Large leafy branches of trees are cut and hung, as shown in Fig 4, by ropes to pegs. They must be closely packed so as not to shake. At first they require looking after, but silt rapidly deposits and the branches become fixed and no longer dependent on the ropes. If the work is carefully done, the result is a smooth, regular and tenacious berm as per dotted line in the figure*. If ever the increase in width, due to erosion, is too great to be met by bushing from the bank, it is usual to construct longitudinal lines of stakes as shown by dotted lines in Fig. 5 and to attach the bushing to them. The stakes may be about 5 feet apart. See also Art. 12. If the length dealt with at any one place is considerable, it is necessary to add cross lines as shown. Spurs of any kind without longitudinal walls are generally unsatisfactory (Chap. IV, Art 1).

* A specification for Bushing is given in Appendix B. See also Chapter IV, Art 10.

Another method is to make up the bank with earth and to revet it with twigs as shown in Fig 6. This kind of work is expensive. Its foundation must be taken down well below bed-level, otherwise it may slip. The twigs are usually the stems of the tamarisk plant which are straight and grow in abundance in the river bed. In their absence other twigs can be used, or reeds. Earth alone will not generally stand (but see Article 4, p. 13).

Staking was at one time used, but it is expensive and unsatisfactory and is now little used. Stakes, generally, 5 to 10 feet long, and 3 to 6 inches thick, are driven, vertically or slightly inclined, and a foot or two apart, into the bed or slope in a line parallel with the bank and near to it. Sometimes long twigs laid horizontally are passed in and out between the stakes so that a continuous wall is formed. The stakes are often forced out of line by scour occurring along them, or by the pressure of detached pieces of the bank. A partial remedy for this is to put in two or three lines, the back one being the higher. Staking is useful immediately downstream of a regulator or fall where the swirl prevents bushing being of use (since silt will not deposit) and renders twig revetment insecure. In other reaches stakes are useful when driven not very close to the bank and with the intervening space filled with bushing, but good bushing alone is nearly as effective, and far cheaper.

The growth of tamarisk and other shrubs or long grasses on the berms and inner slopes of canals where they erode their banks is to be in every way encouraged. (1) Sowing seed or planting young seedlings in winter has been tried but with little success, because the seeds or young plants are submerged and killed in the flood season. They cannot well be planted about F.S. Level, because the bank, if eroded, is vertical, and no berm exists. They often grow of themselves after berms are formed by bushing, etc. Artificial sewing or planting is, moreover, expensive. The question, however, deserves further attention and consideration. Seed sown on wet berms in September might grow high enough to be safe before the following flood season.

Art 4.—*Improvements.* The canals are frequently and steadily improved. The old canals frequently ran in low ground and at low levels. "Lift" irrigation was often necessary. The improvements consist sometimes in re-alignment, and generally in shortening, by means of cuts-off and flattening of the slope, so as to gain command. The flattenings are carried out well downstream of the head reach and so do no harm. Moreover, they are generally accompanied by increase in the size of the channel or at least by altering its cross-section so as to reduce the tendency to silt deposit (Hydraulics, Chapter VI, Art 14). It is always advantageous to amalgamate two or more small canals, because the larger stream has a higher velocity and a less tendency to silt. Amalgamations are effected whenever possible. The command is also improved in some cases by shifting the head upstream. It will be shown below (Art. 10) that such shifting can be used to improve the gradient, and it can of course be used to improve the command,

1) Of course the annual "Jungle clearance" should not be carried out at such places.

the gradient remaining as before. New regulators are also constructed at suitable points. ⁽²⁾ In some places the canals are being supplied with distributaries to bring the water to tracts hitherto served only by long and numerous water-courses which cause waste of water. In other places (notably in the Muzuffargarh District) there are too many distributing channels, and some have to be abandoned, while others are widened and carry increased supplies.

There may also be reaches of the canals where the width is too great. If these reaches are not near the head there may be no great tendency to silt deposit, but if the reach is long there may be a lowering of the water level and it may be desirable to reduce the width. This is a difficult operation if the excess of width is great. If earth is added to the bank it is probably washed away again unless very firm (such earth is not often obtainable) and rammed in layers. It is usual to adopt the methods described in the preceding Article. The inside jungle should not be cleared.

When a canal is remodelled or a new one made, a driving road is provided along the top of one bank. For a distributary a bridle path is provided.

Another great improvement which is constantly being carried out is the building of masonry "Outlets," such as are in use on all perennial canals, for the water-courses. In the absence of such an outlet a water-course generally draws off too much water and has to be closed periodically by native subordinates, a system which gives rise to the greatest possible corruption and injustice and prevents suitable supplies reaching the tails of the channels.

At one time it was usual to allow the cultivators to construct temporary brushwood dams in the canals (when the volume of water was not too great) in order to head up the water. The recent remodelings and improvements of the canals cause the water to be delivered at a higher level and the dams have been stopped except in a very few places where remodelings have not yet been done. The dams not only caused damage to banks, etc., but prevented proper control of the distribution of the water and encouraged corruption, because matters were in the hands of native subordinates, and it was impossible to make sure that a dam which had been sanctioned for a specific period was not allowed to remain far longer.

Appendix C gives certain details regarding the remodeling of Inundation Canals.

Art 5.--*Connecting Cuts.* The Wali Mohamed Canal in the Multan District divides (Fig. 7) into three branches which are run by turns when the main channel does not bring in enough water for all. It might happen that, at A, the Wali Mohamed was dry, while half-a-mile to the west the Secunderabad canal, which was doing well, was discharging, through its escape, surplus water into the river. The connecting channel *ab* was constructed so that surplus water from either canal can be given

(2) When any masonry work is constructed care is taken to put right any defect in alignment at the place.

to the other. This arrangement is both more useful and more equitable than if the water could only flow in one direction. The point *a* is south of *b*, because the Wali Mohamed water level is generally the higher of the two. Similar arrangements could probably be made in a few other cases where two canals are near together and of not very different levels. Regulators are required across the ends of the cut and also across the canals or at least across the low level one. A connecting cut may be of the greatest use and may, in a year or two, repay the cost of its construction.

SECTION II.—CANAL HEAD REACHES.

Art 6.—*General Remarks.* Anything which reduces the silt deposit in the head reach of a canal is of the utmost value and a small change may make all the difference. Any sharp bends should be removed and loops cut off so as to shorten the channel and increase the gradient. The width, supposing the gradient and discharge to be the same, should not be greater than that of the next lower reach. It may with advantage be slightly less so as to give a draw. Anything which causes heading up of the water, such as the continued use of the flood regulator or an influx of water into the head reach at a point downstream of the actual off-take (*Hydraulics*, Chap. VII, Art 6) is a source of danger and may cause serious deposit of silt. The inflowing water may be simply flood water, or escape from another canal, or flood water impounded in a "Pocket" (Chapter III, Art 11) formed by the bank of a head reach with a flood embankment, or with the bank of a subsidiary head. In every case the heading up will be a minimum and may be zero, if the water breaks out again at the opposite bank and this should be arranged for, if possible, and if it does not happen of itself (see below).

For the reason just given, a flood regulator should never be built within, say, three miles of the off-take of a canal if the gradient is steep, and six miles if it is flat. The actual site is generally so fixed that the regulator can be combined with a bridge for a main road or so that it may suit the off-take of a branch or distributary. It may be many miles from the canal off-take. Unless it is so, it should not be used more than is absolutely necessary to reduce supply and cause the escape to work. If there is a flood embankment which has to cross the canal it should be altered if necessary so as to bring the regulator site lower down.

If flood water breaks into a canal it frequently breaks out again on the opposite side and it may form a deep hole in the bed of the canal. This hole may enlarge in all directions, forming a pond whose diameter may be much greater than the width of the canal. When the banks are made up they are carried round the pond forming "ring-banks." In course of time the pond silts up, and the banks can then be brought into proper line. If the damaged place is in high ground little harm may result, except the expense of repairs, but if the ground is low the canal water will continue to escape and be wasted even after the subsidence of the flood and the closure of the breach may be difficult. The rush and disturbance may also cause falling in of the banks for a considerable distance upstream and a short distance downstream of the breach.

If the water merely breaks into the canal head, and does not break out again, the heading up, at the point of influx, may be considerable. It may be desirable to cut the other bank if the ground is not low. It is nearly always difficult, and generally almost impossible, to close bad breaches (i.e. breaches not in high ground) in head reaches until the river finally falls and money should never be spent in attempts to close them unless there is real hope of success and also something appreciable to be gained by success. For the methods adopted for preventing breaches see Appendix E.

Art 7.—*Escapes*. At a flood regulator there should always be an escape, and it should be large enough to carry all the surplus water. Otherwise there will be heading up in the head reach of the canal. The size of the escape can be calculated by taking the difference of the discharge of the reaches *ab* and *bc* (Fig 8). Escapes usually lead back to the river, but occasionally an escape leads into the canal next below. In this case the junction with the lower canal is probably not far from the off-take of the latter, and the heading up caused by the inflow is likely to be detrimental (Art 6). Such an arrangement should not be permitted unless the escape is likely to be slight or unless the water can be again let out of the lower canal close to where it enters.

In floods the country adjoining an escape channel may be all under water, and the reduction in the canal supply could be harmlessly effected without an escape channel by merely opening the masonry escape head and letting the water mingle with the floods. But the country may not all be flooded even when the river is in flood and the escape will probably have to be used at other times of the year. Hence a channel with proper banks is a necessity to prevent damage to property and especially to wheat and other *rabi* crops which have been harvested and stacked in the fields.

An escape of course extends only as far as the nearest creek of the river. It should be inclined downstream at, say, 45° to the general direction of the river. Sometimes, in order to get a short line, it is run out at right angles. Such a channel is likely to have a poor gradient. It is also peculiarly liable to have its banks breached in floods. This may not much matter while the floods last, but the breaches have to be repaired afterwards. In the absence of an escape cuts are sometimes made in that bank of the head reach which is nearest the river, at points where the ground is high, and the escaping water finds its way to the river. Such cuts close of themselves when the floods subside.

Art. 8.—*Difficulties caused by changes in the River*. Owing to the changes which take place in the rivers it is frequently necessary to dig new heads. If the heads could be dug rapidly, and at any time of the year, matters would be greatly simplified, but the excavation requires time and it can only be carried on in the winter and spring when the sub-soil water level is low. Moreover, labour can only be obtained in sufficient quantities in the winter and the early spring. As soon as one irrigating season is over the heads for the next season must be arranged for. The old head may be retained or a new one may be necessary. In arranging for heads regard must be had chiefly to the state of the river as it is at

the time. Some little idea may be formed of the changes which will take place in the immediate future, but beyond that all is mere conjecture. A canal head, whether new or old, may begin to work badly soon after being opened. When serious erosion of the bank takes place just upstream of a canal head the latter may become heavily silted in a few weeks. Or the creek supplying the head may silt up. Or the stream may move away and the water level be in consequence lowered (Chap. I, Art. 8).

On the other hand, the conditions may unexpectedly improve. If the head of a creek is silted, a new head for it may form itself and improve the supply in the creek.

Art. 9.—*Rules for off-takes.* The following are general rules for off-takes :—

- (a) A site where erosion is occurring, or is likely to occur, is a bad one. Many sites in the main stream, or close to it, are thus open to objection.
- (b) A site in a small or silted creek is open to the risk of the creek silting up.
- (c) A site in a large creek is generally good. The site should not be at a bend which seems liable to erosion.
- (d) A site near the tail of a creek, but not so low down as to be close to the main stream, is generally an excellent one. If the head of the creek silts up the supply will be drawn in from the tail.
- (e) A back-water, such as that marked A in Fig 1, is also a good site.

If a canal head works well at the close of one season, say if it is not dry before the 30th September, supposing the river not to be abnormally high, it will probably work well at the beginning of the following season.

Sometimes no good site can be found within a reasonable distance. This may happen when erosion has occurred and the off-take is in the middle of the curved eroded reach. Any new head would have to be some distance from the bank and would therefore form a still longer curve. In such a case it may be desirable to leave things as they are till the following year when the curved stream may have become a creek.

The direction in which the head of a canal points with reference to the river bank is a matter of no consequence. The level of the water in the canal will be practically the same as that in the river, and the velocity and discharge of the canal will be that due to its slope and the depth of the water in it.

Art 10.—*Length and alignment of Head.* The principle of placing the off-take as far up-stream as possible is followed when other considerations do not interfere with it. The slope of a line *ac* (Fig 1) drawn from the water surface at *a* to the water level of the canal at *c* will be greater than the average slope of a line *abc* and the slope of *bc* will therefore be less than that of *ac*, unless the slope of *ab* is comparatively

flat which is seldom the case. A good site for an off-take can generally be found by going far enough, but both funds and labour are limited and practically the length of a new head seldom exceeds two or three miles. A head should not run for a long distance near to the river bank. Such a head offers facilities for new off-takes in case they are needed, but it is open to the danger of being cut in half if erosion occurs.*

If an off-take is carried too far upstream it may result in the supply becoming so great in floods as to be unmanageable.

The Ghuttu Canal, which is in the Muzuffargarh District and takes off from the left bank of the Indus, was, in 1909, supplied from a creek *fg* (Fig. 9) whose off-take was far upstream, and the canal supply in floods was excessive. In the reach *cde* the canal was very near a creek of the river but at a higher level. The canal water broke out of its channel at *d*, fell into the creek and rapidly cut for itself a short channel through which most of the supply escaped into the creek. Efforts to close the breach at first failed, but eventually the Koreshi head, which was disused and closed by dams at each end, was opened and used as an escape. Its length and position prevented its drawing off too much water and scouring out, but it reduced the supply sufficiently to allow of the closure of the breach at *d*. The Koreshi head was then closed. In the year 1910 it was decided to have the canal off-take lower down (than the old off-take above *f*), but the creek *fg* was flowing, even in winter, and could not easily be closed. It was decided merely to open the closed channel *hg*. The water at *g* being higher than that at *h*, some water would pass along *gh*. The water level at *g* would remain higher than if *fg* did not exist and the supply came in along *hg*. If *fg*, in course of time, failed, the supply would come in along *hg*.

Art 11.—*Ground level and Soil.* The ground level in the neighbourhood of a canal off-take is generally high and submerged, if at all, only in floods; but the country is often uneven and the ground may be low, especially if the high ground nearest the river has been eroded. A canal head should be aligned in high ground, otherwise the banks will be expensive, and even then they may break in floods.

The nature of the soil in which a head is dug is of great importance, and trial pits should always be dug to ascertain it.

If it is sand the side-slopes must be made about 3 to 1, instead of 1 to 1 as in hard soil, and even then they must be protected by bushing, otherwise they will be eroded and choke the channel. Berms of about 20 feet (Fig 10) should also be left in sandy soil between the channel and the spoil. The latter is liable to be shifted by rain or strong winds. The question whether it is worth while to dig a new head may turn on the question of soil.

If, as commonly happens, there is an upper crust (Fig 10), two or three feet thick, of hard soil, matters are much improved.

If a head is taken across a low sand-bank matters are extremely bad because the floods will eventually sweep the soil away (that in the

* If a canal is cut into, or likely to be cut into, by the river at some point not very near the off-take a diversion is often made, the off-take remaining where it was.

upstream bank being carried into the canal) and thereafter sweep across the head and probably silt it up.

Art 12.—*Width and Grading of Head.* It has already been stated that the width of a head should not be greater, supposing the gradient and discharge to be the same, than that of the canal downstream of it, but unfortunately it often is greater owing to the upper reach having once been a creek or to its sides having fallen in. If the excess in width cannot be dealt with by ordinary bushing or revetment, longitudinal walls can be tried (Art 4). But the work must not only be very carefully done (great watchfulness being exercised as to the depth to which the stakes are driven and to the quantity of brushwood used) but it requires the greatest attention while the water is flowing, all damage being instantly made good until at last the height of the floods puts a stop to work. Whether training work of this kind is worth attempting depends chiefly on who is to look after it. With care and attention it may succeed admirably, without them it will certainly fail.

It is often cheaper and more satisfactory to excavate a new channel if a line can be found in good firm soil, than to reduce the width of an old one.

It has been stated (Art 1) that the bed of a canal at its off-take is generally at about the low water level of the river. It cannot be dug much lower because of the sub-soil water*. It used to be the custom to place it rather higher in order to obtain a good slope. Of late years it has been the custom to lower the bed, giving a flatter slope but a greater depth of water. The velocity is about the same in both cases, the increase in depth making up for the decrease in slope, but the lowered bed of course gives a greatly augmented discharge. On the other hand, the lowered bed must cause the introduction of water somewhat more heavily charged with silt. Moreover, the ratio of depth to velocity in the canal is greater than before, and this tends to cause increased deposit. Under the old system of high beds the heads of the canals silted more or less. It has been impossible to find out whether more silt has actually deposited since the introduction of the low level system, because, owing to changes in the course of the river, the same head channel is seldom cleared for several years in succession, and also because the quantity of silt deposited depends on other factors, such as the position of the head. Obviously the tendency of the low bed is to silt more than the high one, but the worst that can happen is its silting up till it assumes the level of the high one. This takes time, and while it is going on an increased discharge is obtained.

The most suitable bed level depends a good deal on when the canal is to be opened (Art 1). During the last few years there has been a tendency to revert to somewhat higher levels in the cases of canals not needing early opening.

* The reason why the canals do not usually flow in winter will now be clear. Not only would there be very great difficulty in making the bed low enough when the channel was first excavated, but the same difficulty would be experienced every year in clearing out the silt or digging a new supply channel, and the time available for doing the work would be much less than it is now. It does, however, occasionally happen that a canal, owing to the water-level at its off-take being abnormally high goes on flowing all the winter to the great benefit of the crops.

Art 13.—*Creeks.* If a creek has to be cleared and if, as is usual, it is wider than the canal, it is cleared only for a width equal to that of the canal. The clearance follows the deep bed of the creek (this is generally tortuous as shown in Fig 11) and thus minimises the quantity of earthwork to be done. Clearing a straighter course would be an advantage in some ways, but would give deeper digging and a greater quantity of sandy spoil. It is best to place the spoil from AB, CD, on the high ground at *ab*, *cd*, where it will be above flood level. Even if such ground is cultivated it is best to acquire it. In the length BC the spoil can be put on the downstream side at *ef*. If *gcd* is an old bank of the river and of good soil there is an advantage in following it closely, but this will probably involve too deep digging in places. If a creek is heavily silted, the material sand, and the banks low, the case differs little from that of a head carried across a sand-bank and the chances of success are little better.

Very prominent bends in creeks are sometimes got rid of by “cuts-off.”

The supply in a canal which has its off-take in a creek can often be greatly improved, especially during the early part of the irrigation season before the river has risen much, by placing a dam in the creek below the canal off-take. If the creek carries a good supply, even in winter, the construction of a dam is probably too difficult and expensive to be undertaken, but if the creek is dry or nearly dry in winter a dam is easily made. It is, however, in many cases objectionable. A creek generally carries more water than the canal can draw off. In such cases it is best to let it flow freely. It has thus a far better chance of remaining free and unsilted, especially if the canal off-take is not very far down the creek. In such a case a dam has a strong tendency to cause the creek to silt at its off-take.

Any dam placed in a large creek is extremely likely to be destroyed in floods. However strong the dam is made the flood may rise over the adjoining land and thus convert the dam into an island and destroy it by washing away its ends. A plan frequently adopted is to make a temporary dam in the creek. In the early part of the irrigation season the dam stands and the whole of the supply of the creek goes into the canal. In the floods the dam is carried away. At the end of the season when the high floods are over it may be possible to re-construct the dam, but this is not often the case. The use of a dam in this manner may do little harm to the creek, especially if the canal off-take is a long way down.

Sometimes a creek has to be dealt with so as to enlarge the outfall instead of obstructing it. Thus in the case represented by Fig 12 the portion AB, which was very much silted, was cleared in order to encourage the creek to keep open.

If a creek is cleared year after year it often becomes part of the canal. If wide it may become narrower and the banks less sandy and less liable to be swept away. The portion of the creek below the canal off-take silts up or is shut off by a permanent dam and the creek off-take then becomes the canal off-take.

SECTION III.—SUBSIDIARY HEADS.

Art 14.—*Decision as to Main and Subsidiary Head.* When a canal has two heads the one first opened is called the main head, and the other the subsidiary head. The following are rules for deciding which is to be the main head :—

- (a) The main head should be the one which seems likely to give the better immediate supply. It is not much use having a good supply for maturing crops if there is not a good supply for sowing them.
- (b) The main head should be the longer of the two, because there is then less chance of silt extending down below the junction and so obstructing the flow of the subsidiary head when opened.
- (c) The subsidiary head should have good banks, so that being closed by dams at both ends, it may be completely “boxed up” and no flood water allowed to break into it. A channel to which flood water has access is quite unsuitable as a subsidiary head. It is almost sure to become silted.

Sometimes the decision as to which is to be the main head becomes a matter of judgment, because the above rules happen to be antagonistic to one another, or because there are peculiar circumstances.

Rules (a) and (b) are not often antagonistic to one another. Generally the longest head, *i.e.*, the head whose off take is furthest upstream, will give the best supply unless erosion seems likely to occur at the off-take. If the two rules are antagonistic preference should be given to (a).

Rule (c) may be antagonistic to the others. If so it will generally be because the only head having good banks is the furthest upstream. In this case it will probably be best to make it the main head and to dispense with a subsidiary head.

Art 15.—*Opening of a Subsidiary Head.* The main head usually gives a sufficient supply for the greater part of the season. At first the deposit of silt in the canal or in the feeding creek is small. By the time it has become considerable the river has risen high and the silt has little effect. It is when the high floods are over and the river is falling that the silt begins to have a serious effect, and this is the time for opening the subsidiary head. A suitable date is generally, for the Indus, about the 10th or 12th of August, and for the other rivers about the 20th of August.

Premature opening of a subsidiary head may be disastrous, causing excessive supplies or silting one of the heads if it has a flat surface slope.

In order to decide whether there will be any appreciable gain in opening a subsidiary head and what conditions are likely to result from its opening, it is desirable to have a temporary gauge :—

- (a) At the junction of the two heads.
- (b) In the river at the off-take of the subsidiary head.
- (c) In the canal or river at the off-take of the main head.

The zero levels being known it can at once be seen from the gauge readings what the surface slopes are likely to be, allowing for the rise at the junction consequent on the opening of the subsidiary head. In the absence of such gauges levels of the water surfaces should be taken. In any case the water levels at all three points (a), (b) and (c) should be considered in good time.

When the subsidiary head is opened it is sometimes desirable to close the main head. If the main head is the downstream one, water may begin to flow out through it into the river and it should then be closed, or it may be bringing in a very slight supply, its water being headed back owing to the opening of the subsidiary head, and be rapidly silting, and in this case it may be closed. It may happen, however, that both heads bring in appreciable supplies (this is likely to occur if both heads are long ones or even if the upper one alone is a long one and is the more silted of the two) and both should remain open. No doubt some additional silting is caused in one head or the other owing to both being open, but there is also an additional supply. The question whether the additional supply is worth the additional silting (the cost and difficulty of closing a flowing stream* being also considered) is one of judgment. The question whether it is desirable to close a head is also affected by the information received from stations higher up the river (See Appendix D). Possibly the river may be falling so fast that the head will soon close of itself.

In most cases it is either not worth while to close the main head or not desirable to close it.

Art 16.—*Junction of Subsidiary and Main Head.* At the junction of a subsidiary head with the main head a strong dam is necessary. Otherwise the part near the junction would receive a heavy deposit of fine tenacious silt. The banks *dc*, *cm*, and *pn* (Fig 13) should be protected by fascining or revetment.

It is not practicable to make the junction extremely oblique. The dam *a b c d* must be in line with the banks of the main head. If made in the position *c c f g* the space *b e c* silts up. Such silt might be very stiff and some of it would remain when the dam was cut. If the angle *h d k* is made small the dam *a b c d* becomes long and its construction, watching and removal more costly and troublesome.

Art 17.—*Remarks on Subsidiary Heads.* Special cases may now and then arise and give rise to special measures. For instance, if erosion occurs near the off-take of the main head and it begins to silt up, and the erosion seems likely to go on, it may be desirable to close the head, even quite early in the season and to open the subsidiary head.

It may even happen that what was intended to be the main head is not opened and the subsidiary head is opened instead.

In a large number of cases the subsidiary head is not used. Either the main head continues to give a good supply all the season or erosion sets in at the subsidiary head or its feeding creek fails or the river recedes

* The closure of a flowing stream can sometimes be effected by stakes and brushwood. Occasionally rough trestles are used, made from tree trunks. Sometimes it is necessary to use sand-bags, laying a mattress of them over the bed of the stream and building a weir of sand-bags on it.

from it. It may also (though this is always preventible and can only occur under ordinary circumstances, from negligence) be silted up owing to the dams at its ends breaking (Art 20) or to floods breaking through its banks.

For the above reasons some Engineers of experience think that subsidiary heads are not worth constructing, and they would make it a rule to have only one head. Occasionally, however, a subsidiary head is of immense value. It may save a large proportion of the crops. A subsidiary head is less likely to be useful if there is no one to look properly after it. This depends partly on the *personnel* and partly on the locality. In a very remote locality supervision is more difficult.

SECTION IV.—DAMS FOR CANAL HEADS.

Art 18.—*Object of Dams.* The canals having gone dry in September or October, earthen dams are constructed at the off-takes in November. The object is to prevent water from accidentally entering the canals before they are ready for opening. Any such accident may cause immense trouble. Contractors' earthwork may be unfinished or unmeasured or materials for masonry works may be lying about. The danger may occur during winter freshets or in April or May when the river rises permanently.

Art 19.—*Dams for Main Head.* In order to allow for a slight falling in of the river bank the dam in the main head must be set back some little distance, say 20 to 40 feet, from the actual off-take. To prevent this space from silting up when the river rises, a minor dam is necessary at the actual off-take or as near to it as possible. Setting back the main dam several chains is most objectionable. The whole length may silt up if the minor dam is carried away.

The dams must be parallel to the river bank. If made square to the canal when the river bank is skew, a space is left for the collection of fine tenacious silt. Such silt has at times absolutely prevented a subsidiary head being opened and has interfered with the opening of a main head.

The dimensions of the dams may be :—

			Height above water-level on 15th November.
Top width.			
Main dam	... ..	10 ft.	8 ft.
Minor dam	... ..	8 ft.	5 ft.

If the off-take is from a dry creek the height can be measured from its bed. The material should be got, if possible, from the bed of the canal. Sand does very well. The side slopes of the dams should be protected by fascining. Long twigs are made into bundles and tied up so as to form fascines, and these are laid on the slopes and secured by pegs driven into the ground at short intervals, between the fascines (Fig 14).

If a creek is to be cleared the dam will be at the off-take of the creek (from the river or from another creek which is not to be cleared) and not at that of the canal from the creek unless the dam at the creek off-take is considered to be insufficient.

If there is any creek or channel or depression which is not to be

cleared but by which water can enter the canal or can enter a creek which is to be cleared, it must be closed in a similar manner to the above, but the material need not be taken from its bed and there need not be a minor dam.

On the top of the small dam a grass hut should be made and a watchman should live in it. Whenever there is any danger to a small dam, or whenever any freshet or flood is announced by telegram, and when the river rises in ordinary course in March or April, two men should be employed instead of one. The men should watch, repair, and strengthen the dams. If the small dam is carried away, the hut and men should at once be transferred to the main dam.

Art 20.—*Dams for Subsidiary Head.* For a subsidiary head the dam should, unless erosion seems likely, be close to the off-take with 15 feet top width, height 3 ft. above H. F. L. and sides protected by fascining. If erosion seems likely, the dam may be slightly set back, and if erosion actually sets in a second dam (No 2) should be constructed, say 200 feet downstream. If erosion continues a dam No. 3 should be made directly No 1 is cut away. Its distance from No. 2 may be 200 to 400 feet according to the severity of the erosion. If No 2 is cut away, No. 4 is made and so on.

Art. 21.—*Remarks on Dams.* A dam can be built on the top of sandy deposit, but it should never be built on the top of tenacious silt. The silt should be dug out to bed level and then the dam made.

In opening a canal it is impossible to remove the whole dam. Some of it must necessarily be left and be allowed to be swept away by the water. If time and labour are short, the whole dam may be left to be swept away, a mere cut being made in it. It is better to do this than to delay the opening of the canal. The material in the dam when spread over a great length of canal, causes no appreciable raising of the bed. If any part of a dam is swept away, the officer in charge should see that Government is not charged for the cost of its removal by hand.

SECTION V.—MISCELLANEOUS ITEMS.

Art 22.—*Bridges and Aqueducts.* In the tracts served by Inundation Canals, roads fit for wheeled traffic are somewhat scarce. Masonry bridges are somewhat few. Many bridges suitable for camels, horses, and foot passengers, are made of rough tree trunks stood on end to act as piers, with rough branches laid across them and covered with coarse grass and earth. Such bridges require repair or reconstruction yearly, and not infrequently portions of them fall into the channels. They are gradually being replaced by masonry structures. Bridges of sawn timber are cheap, but do not last. There are very numerous "ghats" or places where the banks are sloped off so that animals or men can get water from the stream or wade or swim across it.

In the winter the people put up numerous temporary aqueducts, rough wooden troughs supported on stakes, in order to carry water raised from wells on one side of a canal to fields on the other side. The canal banks, being generally above the level of the fields, have to be cut through at such places. Before the canals are opened in the spring the people remove the aqueducts and repair the banks. This procedure is

troublesome and objectionable, and is only permitted at places fixed by usage. If a crossing for water becomes necessary at a new place a masonry syphon has to be constructed or a new well sunk, the cost being borne by Government if a new Government channel has severed the connection between well and field, otherwise by the people concerned.

Art 23.—*Hill Streams.* In the Dera Ghazi Khan district there are numerous streams which issue from the Suliman Mountains (these lie twenty or thirty miles to the west of the Indus), and flow towards the Indus. The channels are generally dry, but after rain streams come down and break into the canal at numerous points, generally towards the tails or into the western branches, and break out again on the opposite bank. Much damage is done to the banks, and some silt is brought into the channels, but the water brought in is, on the whole, useful in supplementing the regular supplies which are not generally very good towards the tails of the canals or in the western branches, as these have necessarily somewhat flat gradients owing to the land rising towards the mountains. If the land immediately to the west of the channel rises in going west, the breaches caused by the streams are not repaired, nor is earth from the silt clearances put into them. Canal water may pass out through the breaches, but it cannot go far and the land is generally waste or at least is not damaged by the water.

Proposals have at times been made to construct syphons to pass the streams under the canals at some places where the damage done is severe. There is much difficulty, owing to the fitful nature of the flow, in ascertaining the discharge, but the subject requires attention.

Art 24,—*General Remarks.* The land occupied by most of the canals, and by some of the embankments, was taken possession of by the old native rulers of the Punjab without the formality and accurate demarcation which are nowadays insisted on, and without any payment, but with a proviso that the land should revert to the original owners or their heirs if Government at any time had no further need of it. The boundaries of such land are not, in many cases, very accurately defined.* Government, however, generally exercises full rights over such land, except in the matter of its sale, and owns the trees, unless there is a written agreement to the contrary.

Owing partly to the fact just stated, and partly to the fact that the canals were originally dug by the people, and were for many years maintained by them (the arrangement often being that labour was supplied in lieu of payment of water-rate), the people do not generally realise fully that Government now owns and works the canals, and they damage them and trespass on them in a manner which would never be tolerated on any perennial canal. In many places they have built huts on Government land and much difficulty is encountered in evicting them.† Matters are, however, improving, and the people are learning to respect the rights of Government.

Occasionally, even now, with or without the permission of the

* In such cases, in order to determine the boundaries, it is often necessary to measure the sides of the adjacent fields and compare the results with the entries in the field-maps and field-books which are kept up by the revenue authorities.

† For details and remedial measures see Derajat Circle Order No. 29, dated 11th September 1910.

local officer, a Government channel is cleared by the people if they think it urgently needs clearance and that Government will not clear it at the right moment. This procedure has, in most of the districts concerned, been prohibited on the ground that it imposes an unfair burden on the people and encourages them to consider the canals as still their own and is not creditable to the Government officials who ought to have the work done whenever necessary.

The banks of many of the channels are covered with date palms whose fruit belongs to the people. This gives them a further excuse for trespassing. The roots of the palms and the massive growth just above ground obstruct the banks and channels. It is best to pay compensation and to clear away the trees.

On some Inundation canals it used to be the custom to allow the natives, on payment of small sums, to lop off, in order to feed their goats, the small branches of the *kikar* (*Acacia Arabica*) and other trees standing on canal land. No proper check could be exercised, nor could a small branch be clearly defined. The practice was most destructive and objectionable and has been stopped on most canals.

Besides petty damage the serious offence of cutting a canal bank is not infrequently committed. The object is to let a good supply of water on to land on which a *rabi* crop is to be grown (Chap. I, Art 12). Cutting may be suspected when a breach occurs regularly in one locality. It is a good plan to order a police enquiry to be made when cutting is suspected, but proof is difficult.

Owing to the canals flowing for only a part of the year the revenue staff of subordinates, who see to the distribution of the water and the assessment of water rates, have no revenue work for half the year. Special steps have to be taken to keep them employed in the winter. Works on which they can suitably be employed are keeping the village field-maps up-to-date, posting up irrigation registers, preparing maps and statistics for the remodelling of watercourses and sometimes the demarcation of boundaries.

The "duty" of the water on Inundation Canals is low, being generally about 70 acres per cubic foot of discharge (measured at the canal head) per second, as against 200 or 300 acres on perennial canals. The duty is low because the canals flow only for about five months of the year, because the soil is sandy and porous and because the rainfall is very light. Long water-courses also to some extent, cause low duty.

In matters, such as the observation of discharges, the keeping up of irrigation registers, the distribution of the supply, the fixing of the sizes and sites of outlets for water-courses, the remodeling of water-courses, and the maintenance and extension of plantations, the principles and practice are the same as for perennial canals, except that trees are not planted where they are likely to be cut away by the river.

The chainage of an Inundation canal usually starts from the flood regulator and runs in both directions. The mile posts, etc., in the upstream reach should be of a kind which can be shifted. The same remark applies to the whole canal until all necessary straightenings have been effected.

CHAPTER III.

FLOOD EMBANKMENTS.

[For preliminary information see Chapter I, Art. 12.]

SECTION I.—GENERAL PRINCIPLES.

Art 1.—*Necessity for consulting the People.* When any new line of flood embankment is under consideration the people should always be consulted. An embankment may shut off the floods from land which has hitherto benefited from them and the people may prefer the old arrangement to the new. A single *rabi* crop in the year (the *rabi* is generally the more valuable crop), with freedom from canal assessments, may suit them best. Their villages or homesteads are usually placed on high ground or protected by local ring embankments. There may thus be a temptation for the people to cut the embankment, an extremely easy operation because the men who watch it can be evaded or bribed.* For the above reasons the location of a flood embankment should be very carefully considered, and there should be no delay in providing a supply of canal water to the lands affected.

The fact that the majority of the people affected are not averse to the construction of the embankment is not sufficient. Numerous cases have occurred in which new embankments have breached with such regularity that it seems certain that they were cut. The Talai embankment in the Dera Ghazi Khan District, which was constructed in 1903, breached every year for the first five years after construction. Most of the landowners affected do not seem to have gained by the breaching (though they did not lose much, if anything), but probably some of them gained and they may have caused the breaches. In 1909 huts of a permanent nature were built along the embankment at every 2 or 3 miles and orders were given that sub-overseers and others were to occupy these huts and that the European Officer in charge was to make his headquarters, during the floods, near to the embankment and go along it daily. In June 1909, however, an embankment higher up the river breached and the flood water came down on the landward side of the Talai embankment.

On the other hand, if an embankment scheme is clearly desirable and is agreed to by most of those concerned, it need not necessarily be abandoned, because a minority are against it. When there are many persons interested in maintaining an embankment cutting is not very likely to occur.

If any persons who own property desire its inclusion within the protected area, it is desirable to meet their wishes if for no other reason than that they are likely to help in maintaining the embankment. Occasionally it may be found suitable to construct a masonry regulator in an embankment so that flood water can be let through in volume sufficient to flood particular tracts though not sufficient to damage or destroy property.

* Another, but less frequent, reason for cutting an embankment is to reduce the flooding on the riverward side of it.

This idea is a recent one, but it has been discussed in more than one instance and accepted in one instance, the people even agreeing to pay canal water-rates.

Art 2.—*Alignment.* A flood embankment should not be so near to the river as to be in much danger from erosion, but the ground, as already stated (Chapter I, Art. 1), generally falls, in going away from the river, so that when an embankment is set well back it is in lower ground, more expensive and more liable to breach. The most suitable alignment is a matter of judgment and depends largely on where the main stream of the river is at the moment and on whether it seems likely to shift.

If the main stream of the river has lately made an inroad and cut away an embankment, but has not shifted its course, great caution is needed in fixing the line of the new embankment. In 1882 there was erosion on the Indus a few miles north of Dera Ghazi Khan and a flood embankment was cut away. A new embankment was constructed a mile inland. The erosion recurred and the new embankment was cut away within a few months of its completion (Chapter I, Art. 5).

Embankments are, where possible, made in straight or properly curved reaches. If the bank of a crooked canal has to be utilised as an embankment, the canal should be straightened (Chapter II, Art 4).

A flood embankment, at least at its upstream end, terminates in ground which is above flood level.

Art 3.—*Formation level.* The top of an embankment is generally 2 or 3 feet above the H. F. Level of the river. It should of course be graded parallel to the general H.F. Level, but neither the gradient nor the height of the flood is known with accuracy (Chapter I, Art 8).

There is generally a record or mark of some high flood, and this is taken provisionally as the flood level. Or the level is calculated approximately from the flood readings on the nearest river gauge. If experience shows that the embankment is too low, it is raised.

Art 4.—*Duplication.* In the neighbourhood of Dera Ghazi Khan it has long been the custom to have a double line of flood embankment in places where the first line is in any sort of danger, either from river erosion or from ordinary breaching owing to low ground or bad soil. This should be accepted as a principle for all localities in which the breaching or destruction of an embankment will cause widespread damage. Even if erosion is foreseen it may be very rapid and there may be not time to make a second line. It should be there beforehand. Sometimes the lines are connected by cross embankments whose function it is to localise damage in the event of a breach occurring in the main embankment. Sometimes there is a local embankment whose function it is to protect a local area in case the main embankment is breached higher up, for instance the cantonment embankment (Fig 30).

Additions and alterations, due to changes, or threatenings of changes, in the river may result in a complicated network of embankments as in the case shown in Fig. 30. In this case it was decided that the three lines should be :—

1. M N P Q T V X W.
2. M R S Y X W.
3. D C S K W.

It is necessary that such matters be considered so that proper arrangements can be made for concentrating attention on one line or another.

Art 5.—*Cross-Section.* A suitable cross-section for a flood embankment is top 10 feet wide and 3 feet above H. F. Level, front slope 4 to 1, rear slope 2 to 1. This should be the standard section, though a stronger section can be used if the soil is bad. Sometimes tops 5 feet wide and $2\frac{1}{2}$ feet above H. F. Level or 8 feet wide and 2 feet above H.F. Level, have been adopted with front slope 3 to 1. These may be used for a second line of embankment when the first is fairly safe, being brought up to standard if the first is seen to be in some danger.

Art 6.—*Remarks.* The steps required for safe-guarding the embankments in time of flood are described in Appendices D and E. When the floods form a large sheet of water, the waves on it, due to wind, may do great damage to the front slope of an embankment, and it is often necessary to protect it by fascining (Chapter II, Art 19), which should extend up to 2 feet above H.F. Level and down to 4 feet below it. The velocity of the flood water may also occasionally be sufficient to necessitate such protection. Jungle of all kinds, including shrubs and trees, should always be encouraged to grow on the slopes. It forms the best possible protection. Avenues of trees are also planted on the embankments to give shade. The roots of trees and shrubs do not cause leakage nor is any appreciable damage caused by the uprooting of trees in storms.

At the times of high floods large pegs should be driven in the river-ward slopes of the embankments, at every mile, to show the height of the flood. If a higher flood occurs another peg should be put in. The levels can then be observed at leisure.

Whether the flood embankments have caused the rivers to scour their beds is not known. Probably they are set too far back to much affect the tendency of the river either to scour or to silt.

The flood embankments were in some cases constructed by the natives and are crooked and of irregular section. They are constantly being improved by being strengthened, brought to regular section and having bad bends removed *

SECTION II. EMBANKMENTS AND CANALS.

Art 7.—*Masonry crossings of Channels.* Where a canal crosses a flood embankment there is usually built a masonry regulator provided with gates or moveable beams by means of which the canal supply can be reduced to almost any extent desired. Flood water cannot therefore break down the canal and get out of hand. If the regulator is not in the direct line of embankment, the banks *ab cd* (Fig 15) must be made up so as to form part of the line. Small masonry culverts are frequently made under flood embankments to allow watercourses from canals or wells to be taken across. Such water may be needed on the river side where floods do not come or until they come. Such culverts, if properly constructed, do not cause any danger whatever †

* Large scale plans are necessary for this. See Appendix C, para. 5.

† An embankment was recently constructed in the Muzuffargarh District by the Railway authorities. They refused to allow the construction of a culvert or small regulator (to admit of the irrigation of the lands inside the embankment) on the ground that it would be a source of danger. This is quite contrary to the experience of the Irrigation Department. There are immense numbers of such culverts in the Punjab embankments.

Art 8.—*Crossings without Masonry Works.* It might appear that any gap in a flood embankment (except in ground above flood level) would be wholly inadmissible unless provided with a regulator, but this is not so. In the case shown in Fig. 16, if the canal had no banks, flood water entering at fh could enlarge the gap to any amount. But if the canal banks em gk are strong, the water passing through fh cannot attain either a greater velocity or a greater volume than those due to the section and slope of the canal, and if these are not too great there may be no danger. If, however, the banks of the canal are eroded either just above or just below the crossing, the angles at f and h may be cut through and an open breach result.

The same thing may occur if a breach in the canal bank occurs near to f or h and enlarges itself. Crossings of the kind under discussion are not usual except for small channels (generally only water-courses) in not very low ground, and in cases where the embankments were constructed by the people themselves. Similarly an escape in its course towards the river can cross an embankment without a regulator if its banks are strong and above flood level so that they will not breach if flood water comes in through the gap when the escape is not working, or if the escape water is headed up by such flood water.

A subsidiary canal head may cross a flood embankment without a regulator, and without any of the precautions just indicated, provided that a strong dam is placed across the head in the line of the embankment and is not cut till the floods are over. But such an arrangement prevents the subsidiary head from being used early in the season if emergency arises and even if used later there is a chance, at least in some rivers, that a flood may still occur.

In any of the above cases inconvenience would be caused to those in charge of the embankment owing to there being an unbridged gap.

Art 9.—*Utilisation of Canal Bank as Flood Embankment.* It is a general rule to make a flood embankment (Fig 17) follow a canal bank when possible. There is a saving in earthwork. The embankment is kept damp and rats do not burrow into it so much. Except in the reach upstream of the regulator the embankment follows the bank nearest the river and has water on both sides of it (Fig 18). Such an embankment is safer than one with no canal along it.

The figure shows a case (and this is the usual one) in which the F.S. Level of the canal below the flood regulator is a good deal lower than the H. F. Level of the river. If this is not so, the advantage to the embankment from having water on both sides of it is still greater.

The embankment, even downstream of the regulator, may follow that bank of the canal which is away from the river, but the arrangement is a bad one and is rarely adopted. The embankment has water on only one side of it, and nothing is gained in the way of safety. Moreover, the other bank of the canal must be made as high as the embankment or be in danger of being topped or breached. Also the water-courses for irrigating the country have to be taken under the embankment by masonry culverts.

Art 10.—*Effect of Canal Bank outside Embankment.* In the reach of a canal upstream of the flood regulator the water level in the canal at b

(Fig 17) is generally slightly above the flood level at c , because the canal gradient is flatter than the flood gradient, but this may not always be the case, especially if there is silt in the canal head, or if the floods are obstructed by local patches of high ground. If a breach occurs it may be difficult to ascertain, after the flood has passed, whether the water flowed from b to c or *vice versa*. The bank *geck* may seem to be of little use. It is, however, of use, because in the event of a breach occurring (say at h) in the flood embankment da , the volume of water passing through the breach is restricted to what can enter the canal at fg . This volume may, in the case of a large canal, be great, especially if the breach is near enough to the off-take to cause a heavy draw in the reach jh (Hydraulics, Chapter VII, Art 6), but it would be greater if the banks *geck* and fd did not exist.

It is necessary, however, to guard against the idea that *geck* is the flood embankment and has to be watched and protected while da is neglected. Money has occasionally been wasted in attempting to close breaches in banks such as *geck* while water was passing through the breaches.

It will be seen that conditions may be somewhat complicated, and it is essential that the lines which are to be considered as flood embankments and are to be watched and dealt with as such, should be clearly defined.

A general plan of the River zone in each sub-division should be kept up by the Executive Engineer (and a copy by the Sub-divisional Officer), and every year, as soon as the lines of flood embankment are settled and taken in hand they should be shown in such a way as to leave no room for doubt what the lines are and where they cross the canals. The H.F. Levels of the year should also be shown at convenient intervals.

Art 11.—*Pockets*. If the country smt (Fig 19) is liable to be flooded, and if the canal head mt has a strong right bank, this bank and the flood embankment st form a "pocket." The water in the pocket is nearly still. There will be flow along sxm , but hardly any along stx . The flood level at t rises practically to the level at s . If the pocket is not deep no harm may result, but otherwise there may be great danger and special measures must be taken to avert it. New pockets are always liable to occur when new canal heads or new embankments are made, or when a breach occurs in a first line of embankment, and care must be taken not to overlook them.

The simplest method of dealing with a pocket is to weaken the canal banks at some point between n and t so that floods will break across them. This case has been already mentioned (Chapter II, Art 6). The arrangement is hardly practicable if the ground near nt is low, because in that case the canal water would continue to escape after the floods had subsided, but otherwise it is a good arrangement, especially if the crossing point is a long way from the off-take *

Another method of dealing with a pocket is to make a "tie embankment" sx . This, however, shuts off the floods from the land stx and this

* To augment the canal supply by cutting only the right bank between n and t is objectionable, as explained in Chapter II, Art. 6, and it would not relieve the pocket sufficiently.

may be objectionable (Art. 1) even if canal water can be given to the land. It is probable that in some cases a regulator in the embankment would solve the difficulty. On the Chenab Canals in the Mooltan district some deep pockets were closed by embankments, but they were cut by the people. It would have been better to have adopted the plan of letting the water out of the pockets by weakening the banks.

In the case of a pocket caused by a subsidiary head like pn , a cut in both banks between y and n is not open to much objection, provided the ground is high, if a dam is made at y in addition to the usual one at n , so that the flood water will not have access to the channel py . The banks in yn will be left unmade or will be removed, but as the subsidiary head is not likely to be used till after the floods, the canal supply is not likely to escape at yn . If the head is opened during the floods there will be escape, but it may not be of consequence.

If there is no way of relieving a pocket, the whole bank $stxm$ must be raised to a suitable height above the water level at s . If the pocket is shallow, this is easy and safe. Even a right-angled bend bac (Fig 20) causes strain on the embankment. There is flow along bc , but little along bac . The F.L. at a rises above that at c . The embankment bac should have a flat gradient, the top at a being higher than that at c .

SECTION III.—DESCRIPTION OF SOME RECENT CASES.

Art 12.—*The Magassan Canal Head and Embankment.* The Magassan Canal (Fig. 21) is situated in the Muzuffargarh District on the left bank of the Indus. It derived its supply at b , sometimes from the Brohi head and sometimes from the Chitta creek which is one of the eastern network of creeks (Chapter IV, Art. 9). The supply in the Chitta depends partly on the extent to which dams are thrown across the creeks by the cultivators of that district. A few years ago an embankment bcd was made to close the pocket $dhab$, and a distributary pne was made to give canal water to the area thus shut off from river floods.* In 1909 the channel ba had become so enlarged that it brought down to the regulator at a more water than could be dealt with and, the channel being somewhat crooked, the left bank which formed part of the flood embankment, was constantly being eroded. The escape af ran too nearly at right angles to the river and was often breached by the floods. The proposals submitted and approved in 1909 were to build a regulator and escape head at k (this would have been the best site originally) to enlarge the narrow, but straight, abandoned channel kg , and make cuts ga , lk and mk , the last being to straighten the Chitta where it had a tendency to work towards the embankment.

Art. 13.—*The Nur-Dhundi Canal and Embankment.* This case is one of the most interesting on record and illustrates the enormous trouble caused by the westerly movement of the Indus. The Nur-Dhundi Canal, formed by the amalgamation of the Nur and Dhundi Canals, is in the Dera Ghazi Khan District on the right bank of the Indus. In 1908 the off-take was at a (Fig. 22). The line of flood embankment was $mdnqbztrsvw$ the line crossing to the left bank of the Nur-Dhundi at z and to the left of the Dhundi-Kutab at v . A local second line of embankment was nxz . Early in 1908 serious erosion began near b . The canal and the embank-

* The distributary came from another canal and passed through a disused regulator at n .

ment *xt* were cut through, the regulator and rest-house at *z* destroyed and the floods travelled down the country parallel to the river for 50 miles doing enormous damage. Fig. 22 shows the state of affairs after the flood season, *i.e.*, in October 1908. The channel Bc C D was reported to be the main stream though narrow. The proposals formulated in October 1908, for new heads and embankment, are shown on the Figure by dotted lines. The programme was the heaviest ever attempted on Inundation Canals in one locality in one season. The works were put in hand, but the channel *cdekfg* could not be completed in time for the opening of the canal in May 1909. Its length was some 10 miles and it ran in low ground necessitating heavy banks. The left bank of the portion *kfg* was, however, completed in time to act as a flood embankment and the canal was supplied through *hg*, the Sohan canal, which was to have become a branch of the Nur-Dhundi, being supplied through its old head *lnk*. A regulator was built at *e*, but not used. The embankment was not cut through at *d* and the upper line of embankment was *mdn* and thence along the left bank of the Sohan *nk*. There was an old regulator at *n*. The embankment *gr* was constructed. A masonry head for the Pharia distributary was made at *f* in the new channel, but as the latter was not finished the Pharia was supplied by a temporary channel from the Sohan below *k*.

Early in June 1909 the flood water from the river came up to the embankment *gr*. The earthwork was new and the embankment breached. The breach soon became hundreds of feet wide and the country was again inundated. The floods had not attained their full height (they never do so in June) and yet the water came up to what was supposed to be High Flood Level. This is an instance of the effect of the main stream being close to the bank (Chapter I, Art. 8) and the embankment *fgr* being nearly at right angles to the course of the river (Art. 11). The old embankment was reported to have been duly cut at *t* to avoid a pocket. After *gr* had breached, the banks of the channel *hg* were cut at A to lower the flood level along *kfg*. The flood water flowed swiftly and eroded the embankment *fg* which was with difficulty protected by short spurs. The canal water eroded the right bank (here a flood embankment) *gp* and a new bank had to be made just behind it.

After the floods the main stream altered its course and the two great bends Ba and CD became minor arms. The arrangements made in October 1909 were to construct a first line of embankment *euy* (with an escape running alongside it and to the left of it as far as *u* where it was to be turned into the river), to abandon the head *hg*, where it was greatly damaged, and would have crossed the above-mentioned embankment, to abandon the embankment *gr*, which was greatly damaged, to complete the channel and embankment *cdekfg* (the embankment crossing at *e* to the left bank) and to construct an embankment *pv* with a channel alongside it and west of it to act as a connecting channel and enable surplus water from the Nur-Chundi to be sent into the Dhundi-Kutab canal. This programme was, probably, all carried out. The plan also shows a tie embankment which had been made (rather near the river) to close the pocket made by the two heads of the Dhundi-Kutab canal. This embankment was cut through by the river.

CHAPTER IV.

RIVER TRAINING WORKS.

(For preliminary remarks see Chapter I, Art. 12.)

SECTION I.—SPURS.

Art 1.—*Description of Spurs.* Spurs have been used on two occasions where the Indus had been eroding its right bank and where further erosion was feared. The spurs were made of small trees dragged to the river's edge by bullocks and weighted with nets filled with boulders brought from the Suliman hills which lie twenty miles to the west. The first set of spurs was made in 1878-79 in the reach marked AB (Fig. 23). There were about ten spurs extending over half-a-mile of bank.* The lengths attained were generally 20 to 30 feet, but one longer one was easily made in a shallow place where the current had deserted the bank. When the river rose in 1879 it took a new course *cd*. This change was obviously not due to the spurs. The new course began five miles upstream of the spurs. The old channel soon silted up and the spurs became buried in silt. They remain so to this day and are now in the midst of fields and villages. The cost of the spurs was about £5,400.

The second set of spurs was made in 1882-83 in the reach marked EF (Fig 24). They were fifteen in number. Their lengths are not known. When the river rose in June 1883 it carried away eight spurs in a few weeks. At the remaining spurs the river ceased to exert any westward force and silt accumulated around them. They, however, disappeared in the year 1885, 1886 and 1887, when the river again attacked its western bank. The whole cost of the spurs in 1882-83 was about £10,000.

Spurs, at least in a river with a soft channel, are essentially bad in principle because they form "abrupt changes" in the stream (Hydraulics, Chapter I, Art. 17 and Chapter VII, Art 2) with the accompanying disturbance and scour. As soon as a spur is long enough to cause any appreciable obstruction of the stream, a rush of water round the end of the spur is caused and a hole is scoured out. Into this hole the spur keeps subsiding and its prolongation, or even its maintenance, is a matter of great difficulty. A high flood probably destroys the spur. The proper principle is to give a continuous protective lining to the bank and to avoid local projections or obstructions. The Railway Engineers of India have long recognised this principle (Section II).

Art 2.—*Floating Spurs.* In connection with the spurs of 1882-83 attempts were made to control the river by means of barges carrying shutters which could be let down like drop-keels. By placing several barges in a row, a long line of shutters was obtained forming a floating spur. The principle was sound in one respect, namely, that the spur could not be destroyed by the river. The shutters, however, reached down only 5 feet below the water. The effect must have been to cause a rush of

* The reach is marked *ab* on Fig 36.

water under them, analogous to the rush round the end of a spur, and to cause scour of the bed. The shutter barges were soon given up. They might be more effective if the shutters could be made to reach down to the bed, but they would still cause abrupt changes and disturbance.

SECTION II.—THE DERA GHAZI KHAN STONE EMBANKMENT,
HURDLE DYKES AND LEADING CUT.

Art. 3.—*The Stone Embankment.* In order to protect the great Railway bridges of India, the Engineers have, for many years past, adopted longitudinal embankments made on Bell's principle, somewhat as shown in Figs. 25 and 26. If the river at any particular point erodes the bank and comes near the embankment, the stone apron at that place falls in and forms a pitched slope. If erosion still continues, the rest of the stone begins to fall in. Usually there is a line of rails along the embankment and thus more stone can easily be brought to any point from reserve stacks which are placed at convenient intervals.

In 1888 it was decided to construct an embankment on this principle to protect the town of Dera Ghazi Khan. The river had come very near to it. The town contained some twenty thousand people. It was owned by private individuals, but its destruction might have been succeeded by that of the cantonment where costly Government buildings exist. The embankment was to be nearly straight, to contain about two million cubic feet of stone and to cost about £47,000. The cost was to be divided into equal shares between the Government of India, the Local (Punjab) Government and the Municipality of Dera Ghazi Khan. The embankment (Figs 27 to 34) ⁽¹⁾ was begun in February 1889 and work for the season was closed in May of the same year. By that time most of the work had been done. It was completed in the following year, its length being 5,221 feet. Up till 1895 the main stream of the river did not come into contact with the work. In 1895 the river somewhat eroded its right bank upstream of the embankment, and the upstream end or nose of the latter was strengthened. In 1896 four earthen embankments, in the form of spurs with cross heads of stone, were constructed. In 1896, 1897, and 1898 the embankment was subjected to the force of the main stream without being damaged appreciably. In 1900 the river cut deeply into its western bank upstream of the stone embankment. The four spurs and their heads were carried away. Some small additions were made to the upper end of the embankment. No money for heavier works was forthcoming.

Art 4.—*Hurdle Dykes.* In 1900 the situation, as just described, was one of great danger. In 1901 it was worse. In that year the Viceroy of India, Lord Curzon, visited Dera Ghazi Khan, and it was then decided to undertake further works for the protection of the town. The object was to close the western stream (it was the main stream) immediately above Dera Ghazi Khan. The work took the form of "Hurdle dykes," each dyke consisting of three lines of long piles driven into the bed of the stream (which was to be protected with mattresses made of fascines) and extending right across it with their heads above flood level. The positions of the dykes (three in number) are shown in Fig. 30. The idea was not to wholly stop the flow of the water, but to obstruct it so

(1) The cantonment and various embankments are shown in Fig 30 and omitted in the others.

much that silt would deposit, the channel become choked up and the water find a course elsewhere. The work was thus partly a "Diversion" work and not merely a "Protective" work like the works hitherto mentioned. The work was under the superintendence of the late Mr. E. F. Dawson, who had seen similar work in the United States. The work was begun in March 1902 and was in progress in May of the same year when an unusually early flood put a stop to it. The dykes had at this time advanced considerable distances from the right bank of the stream, but none had been completed. Dykes Nos. 1 and 2 were for the most part carried away. The river, however, took a new course starting from a point far upstream, the western channel became a creek, and the remains of the dykes were soon embedded in silt.

Art. 5.—*Destruction of the Stone Embankment.* In 1906 (Fig. 31) the main stream again cut into its right bank, though not so deeply as in 1900 and 1901, upstream of the stone embankment. In June 1908 it was as shown in Fig. 32 except that the sand-bank marked *a* was largely submerged and the stream *cd* had become very large. The usual procedure in such cases is to strengthen and protect the upstream end or "nose" of the embankment, and it is sometimes said that when the stream has cut in so far that its course makes a semi-circle (Fig. 35), it will straighten itself by taking some "short cut" upstream of the embankment. The likelihood of this occurring must depend upon whether or not there exist natural facilities for any short cut. At Dera Ghazi Khan it did not occur. The stream eroded the rear of the embankment *ob*, the stone fell in and was swallowed up, and the stream broke through the embankment, leaving the nose *b* standing for a time, as an island. Thereafter the embankment, except the nose, was rapidly destroyed. The state of affairs in October 1908 is shown in Fig. 33 and that in September 1910 by Fig. 34.

The stone embankment was a half-measure and so did not succeed. The mile actually made was not in the best position. It should have been in the position shown by the dotted line *ab* on Fig. 29. This might have been more expensive, because some gardens or buildings would have come in the way, and it would also have left some of these unprotected, but the protecting effect to the town would, because of the reduced chance of outflanking, have been far greater. In 1900 or 1901 instead of a new kind of work being tried, the stone embankment (the efficiency of these works had been amply tested at the railway bridges and at Dera Ghazi Khan itself) might have been extended along the line *bc* so far as funds permitted.

Art. 6.—*Leading Cuts.* Attempts to train the Indus by excavating cuts to lead the river to the east have not often been made. Cuts made near the river by manual labour can only be dug to a foot or two below the level of the water because of the sub-soil water. Cuts made in winter may, no doubt, have 5 or 6 feet of water in them in May and June, but they are more likely to silt again than to scour and enlarge themselves. They would be expensive in any case and enormously expensive if dredging were resorted to. They would be Diversion Works and not, like nearly all the other works hitherto mentioned, mere Protective works. A shallow cut *ab* (Fig. 23) was made in 1879, but it immediately silted up

again. A cut *PQ* (Fig. 36) has lately been excavated near Dera Ghazi Khan, but it has not succeeded.

SECTION III.—GROYNES.

Art. 7.—*Description of Groynes.* In 1887, about the time when local works for the protection of the town of Dera Ghazi Khan were beginning to be considered, Mr. R. A. Molloy, the Executive Engineer in charge of the Dera Ghazi Khan Canals, seeing the increasing difficulty (*vide* Chapter III., Art. 2) in keeping up the marginal flood embankments (throughout the whole length of the 70-mile reach and not merely at Dera Ghazi Khan) and being aware of the uselessness of constructing spurs in the main stream, proposed to adopt a system of groynes or earthen embankments constructed across the sand-banks and creeks in the manner shown in Fig. 1. He claimed for these that a groyne would (so long as it lasted and was not breached by floods or destroyed owing to the ground on which it stood being eroded by the river), *firstly*, prevent the main stream from breaking down any creek which was crossed by the groyne, and *secondly*, cause a deposit of silt, thus adding material to the west bank of the river and in the long run checking the westward movement. The first of these contentions is undoubtedly right, the second not so good. It must be remembered (Chapter I., Art. 9) that any sand-bank or low ground, unless and until it is eroded, nearly always receives deposits of silt without the aid of any groyne, and that a groyne, though it obstructs the water and favours silt deposit on the area upstream of it, yet tends to prevent the access of water to the area downstream of it and may thus reduce the silt deposit there. Some groynes on a small scale were constructed by Mr. Molloy in 1888 and 1889, and Government then accepted their principle and they have been constructed regularly ever since. A groyne is not usually made unless the creek or creeks to be crossed are so shallow or so small that they go dry in winter or discharge only small volumes. The closure of a creek with a considerable discharge is difficult and expensive.

The top of a groyne is generally about 7 feet wide and 3 feet above H. F. L. The material is nearly always sandy and may be pure sand. The sides slope at about 2 to 1 and are protected by fascines made of tamarisk which grows abundantly on the sand-banks as soon as any silt has deposited. The landward end of a groyne abuts on high ground above flood level or is carried on till it meets a flood embankment. The riverward end is generally at a point where the sand-bank is high. To prevent damage by a rush of water along the groyne, and especially round its end, short spurs are sometimes made along it at intervals, and there is usually a strong protection of brushwood and stakes at the end. During the whole period from May to September each groyne has to be closely watched by a gang of men who at once make good any damage and stop up leakages which would otherwise become open breaches.

Art. 8.—*General effect of Groynes.* It is, *a priori*, unlikely that the construction of any one groyne will be followed at once by a local easterly movement of the river or even by a cessation of its westerly movement. If any such movement or cessation does occur, it could never be said that it would not have occurred in the absence of the groyne. One

way to test the efficacy of the groyne system is to observe the general movement of the main stream in the whole reach over a long period of time.

In 1887 the stream was well to the west. In 1888 it had moved eastward. In 1887 there were no groynes and in 1888 only one. A dotted line representing the mean position of the main stream in these two years is shown on Fig. 36. A firm line shows the mean position of the stream in 1905, 1906 and 1908. This line is, on the whole, slightly to the west of the dotted line. Nothing is to be gained by comparing intermediate years. They show, as compared with the line of 1887-88, sometimes an easterly and sometimes a westerly movement. The groynes existing in 1908 are shown by thick firm lines, those which had formerly existed, but disappeared, being shown dotted. In some cases their positions are only approximately known (Chapter V., Art 14), but the information given on the map is enough to show what groynes have been made.

The following is a statement of all the groynes which have been constructed. On Fig 36 the number only (column 3 of the statement) is given :—

Name.	Year of construction.	Serial number.	REMARKS.
Khosawalla	1888	1	Mostly destroyed in 1899.
Awaniwalla	1889	2	
Fazalwah	1890	3	
Sakirawalla	"	4	
Adamgarh	"	5	
Borwalla	1892	6	
Fauja	"	7	
Hairo	1894	8	Mostly destroyed almost as soon as constructed.
Sohan	"	9	
Nur (upper)	"	10	
" (lower)	"	11	
Shahban	"	12	
Chibri	"	13	
Kutab	1897	14	
Kot Daud	"	15	
Panjtan	1898	16	
Kaku	1899	17	
Kattewalla	"	18	
Borwalla	"	19	
Rawan	1900	20	
Sahiban	"	21	
Pir Adil	1901	22	
Pitafi	"	23	
Gadai	"	24	
Cantonment	1902	25	
Sahiban	1905	26	
Hairo Head	1906	27	
Borwalla	1908	28	Bank of the Hairo Head of the Dhundi-Kutab Canal. To replace the second Borwalla, most destroyed in 1907.

Independently of lines shown on maps the continued westerly progress of the Indus is proved by the damage done. At A (Fig 36), at the extreme north of the 70-mile reach, the river has encroached little, if at all, since it moved east after its inroad of 1878 (Art 1). In the reach BC it has almost continuously attacked the western bank at some point or other and it destroyed the town of Dera Ghazi Khan in 1910. At D it destroyed a rest-house and regulator in 1908 (Chapter III, Art. 13). In the reach

DE attacks have been frequent and a regulator of the Dhundi-Kutab canal was destroyed in 1904. On the eastern bank no damage of any consequence has occurred since 1893.

The total cost of the groynes up to 1909 has been about £40,000 excluding the cost of some groynes, such as the Khosawalla, which are really the banks of canal heads and would have been made in any case.

Art 9.—*Further Remarks on Groynes.* There are on the east bank of the Indus, at distances from the river ranging from a mile to 6 or 8 miles, numerous permanent creeks (Fig 3) which have doubtless been left by the river as it moved westwards. Across these creeks earthen dams are every year thrown by the natives so as to cause the neighbouring lands to be flooded. This is done for purposes of cultivation. It has been alleged that this system of dams is the cause of the westerly movement of the river, and this was used as an argument in favour of undertaking the system of groynes just described. This view seems to be erroneous. It would have more claim to consideration if the dams caused the creeks to silt up and become obliterated, but this does not happen. It has been seen that in twenty years the construction of groynes on the west bank has not driven the river east. All creeks or channels across which dams can easily be thrown, are too small for their closure to appreciably affect the main stream except in so far as the main stream is prevented from actually breaking down them. The creeks on the east of the Indus are too long and tortuous for this to happen. They seem to be an effect of its western movement and not a cause. When the river happens to move temporarily to the east, creeks are left on the west, but they are cut away when the river moves west again, and so do not become permanent.

It can be said for groyne construction that it was a much more ably conceived and more practical system than that of constructing spurs or other such works in the main stream. It is possible that in the absence of groynes the river would have moved still further west than it has done. It also seems probable that the construction of groynes has not been pushed far enough, and that more closures of flowing streams should have been undertaken. Mr. Molloy's wishes in this respect were not always complied with by Government. Such a policy would, of course, have involved more expenditure, but half measures are generally wrong. It seems desirable now to give more attention to groynes (both in construction and in watching and maintenance) and to seize every opportunity of effecting closures of flowing streams on the west and of constructing leading cuts from west to east. Although the town of Dera Ghazi Khan has gone, the cantonment remains. This, and even the new native town which is probably to be built a few miles to the west, will be destroyed if the river continues to move to the west. Moreover, some of the flood embankments are being pushed so far to the west that they are getting into very low ground, and their maintenance is becoming increasingly difficult.

SECTION IV.—PROPOSAL FOR LINING THE BANK WITH TREES.

[This proposal was submitted to the Chief Engineer in 1909 and received his general approval. It can be carried out quite independently of groynes or other works].

Art 10.—*Trees for River Bank Protection.* The bushing of canal banks has already been described (Chapter II, Art 3 and Appendix B).

A berm of tenacious silt is formed. It is all the stronger for having the branches buried in it, and it lasts for years. The system is in accord with the principle enunciated (Art 1) of providing a continuous bank lining and avoiding local projections.

A precisely similar arrangement could be made on the Indus if trees, with their roots upwards, were used instead of branches. An estimate for lining the bank with trees was prepared in 1892, and some work was done, but it failed. Similar attempts have failed on the river Markanda. The reason of the failures was undoubtedly the smallness of the trees used. To haul really large trees several miles is impracticable, and such trees could not be obtained in anything like sufficient numbers. Bushing fails in exactly the same way if the branches used do not reach down nearly to the bed or if they are not packed closely enough, but when the branches are of the right size and sufficient in number, bushing never fails. Trees would succeed on the Indus if really large and used in great numbers.

Art 11.—*Proposed Belts of Trees.* The plan proposed is to grow trees along two belts parallel to the river, each belt to consist of about four rows of trees. The soil of the Dera Ghazi Khan District suits *sheesham* trees admirably. If the first belt was not eroded by the river, and the trees grew to be, say 40 feet high (this they would do in fifteen or twenty years) the river would never get through the belt. When it attacked any place the trunks of the first row of trees would be chained to the second row. The first row would fall in but they could not be carried away. If the second row showed signs of falling they could be chained to the third row (Fig 37). Let anyone walking down an avenue of full-grown trees, 40 or 50 feet high, with great spreading branches, take note of them and consider what river could move a row of them when chained to the other standing row or could continue to erode a bank which was lined with them.

The Indus is seldom more than 40 feet deep. Full-grown *sheesham* trees are 50 feet high, and they may attain this height in twenty years. Even if the trees, when a belt was attacked by the river, were only 30 feet high, *i.e.*, in say twelve years after planting, they would be more numerous, because of fewer thinnings, and it is probable that the river would not get through the belt. No doubt the river might cut through the belt while the trees were quite small, but it would only be here and there, and it would recede again so that the eroded lengths could be again planted.

Art 12.—*Proposed Alignments of Belts.* An ideal arrangement would be to have each belt about 150 feet wide and containing a dozen rows of trees. Such a belt, even if it followed a line of canal, embankment or road, would be very expensive. The system being practically untried, it would not be desirable to incur such expense. It is therefore proposed to grow the trees on the existing embankments and canals, and this is the reason for fixing on four as the usual number of rows. There is not

generally room for more. It is not necessary that a belt be continuous provided that, at any break, it is set back as per Fig. 38. The upstream ends of the belts should turn in to the west so that the line cannot well be out-flanked. The movements of the river are so uncertain that it is difficult to say how far back a belt should be set. Probably it would be suitable to plant every channel and embankment which does not seem to be in danger of early erosion unless, as occasionally happens, the soil is bad and unsuitable for trees. If in any place only one line can be found, an extra number of rows might be planted there. The rows should be about 15 feet apart, the trees in one row being opposite to the gaps in the adjoining rows.

Art 13.—*Remarks.* The planting of trees along canals, embankments and roads is nothing new. It is regularly carried on. The soil of Dera Ghazi Khan, as already remarked, is admirably suited to *sheesham*. Afforestation and tree-growing are desirable things. The Government of India has frequently given expression to this view, and recently has laid stress on it. The planting of four lines of trees instead of, say, one or two, will merely be an extension of current operations. The planting of trees on the berms of wide canals (this is necessary in order that the rows may not be too far apart) is certainly an innovation, but one that will cause no great harm. The trees are not often blown into the canals. Planting on berms offers great facilities and was, for this reason, proposed not long ago by one of the Sub-Divisional Officers. The proposal is simply to give increased attention to the planting of trees on the canals and embankments selected for the belts and to plant and keep up four rows of trees along them. If the cost is heavy, operations can be curtailed on other channels at a distance from the river.

When any new embankment is constructed a little extra land might be acquired on the landward side and trees planted on it or any trees already growing on it allowed to remain.

CHAPTER V.

OUTLINE OF ANNUAL WORK AND PROCEDURE.

[This Chapter is based on general orders which were in force, in 1910, on most of the Inundation Canals of the Punjab. Some of the orders are long, but experience has shown them to be necessary].

SECTION I—GENERAL SKETCH OF WORK.

Art 1.—*The Annual Works.* The canals have to be ready for opening by 15th April even if there is no intention of opening them quite so soon. About 12th April the local labourers go off to reap the *rabi* harvest. The work on canal heads and diversions is often very heavy. It is necessary to aim at completing these works by 31st March. If any portion of a canal clearance cannot be completed, and water must be admitted, a ditch or gullet should be dug along it. This procedure is seldom necessary, and never when proper arrangements are made.

If groynes have to be made, those portions of them which are in the river bed, or in low ground, should be finished by 1st May and the rest by 15th May, dams being thrown across any depressions or channels likely to bring in flood water. If an escape has to be constructed or altered the work can probably go on till June. Floods seldom spread over the country till 1st June or 15th June, and work on embankments can go on till then. If a flood embankment or groyne is not likely to be ready in time, any lengths which are in low ground, where floods are likely to come, should be made first. The work can also be completed throughout its whole length to a smaller section than that intended, so that it will stop low floods, earth being then added to the back and top.

New flood regulators, when required, take long to build, and should be taken in hand very early, bricks being manufactured before the canal goes dry.

All the above works, namely, canal heads and diversions, groynes, escapes, flood embankments, and regulators, may be termed the river zone works. They form the bulk of the annual works.

The clearances of other reaches of the canals and of the branches are not so heavy. The strengthening of canal banks can be attended to, more or less, at all times of the year. New bridges or regulators, other than flood regulators, may take long to build, but can be arranged for beforehand or, if delayed, the channel can be diverted.

Ordinary repairs to masonry works can generally be done within two months and are not nearly so urgent as the earthwork.*

Obviously the earthwork on the canal heads and diversions is the first thing to be started, and the earliest procedure should be directed entirely to it, the other work following in due course. †

* All masonry works should be examined, as soon as time permits, by the Subdivisional Officer, and proposals for repairs sent in.

† It is an excellent plan to prepare a calendar of operations for the year showing the dates of every important step beginning with the commencement of inspections (Art 5) and including all survey and earthwork operations, brick manufacture, submission of reports, etc. Such a calendar is of special use to those lacking previous experience.

All the works on which the opening of a canal depends should be ready by the 31st March * and this generally requires considerable effort, especially as remodelling or bank strengthening are probably going on at the same time.

A great deal depends on attending first to those cases where heavy work is likely to be necessary or where land has to be acquired or where the orders of the Chief Engineer are required. Such cases can be foreseen in time to admit of precedence being given to them.

Art 2.—*Procedure for Annual Works.* As soon as the highest floods are over, proposals (in the form of preliminary reports with sketches) have to be made for the river zone works to be undertaken in the following winter. As soon as orders on these proposals are obtained, levels, etc., have to be taken, grading decided on and detailed proposals worked out. A survey of the river has also to be made during the winter.

The detailed procedure on all the above matters is dealt with in Sections II. to IV.

All snags, obstructions, portions of damaged temporary bridges and irregular silt-heaps, except in cases where the bed of the channel is too low (Chapter II. Art 2), should be removed directly the canals go dry. This enables a start to be made at once and gets together a certain amount of labour. Such work is within the power of sanction of the Executive Engineer himself.

Land urgently required for canals or embankments or any other works can be quickly acquired under an urgent clause in the Land Acquisition Act, but the Northern India Canal and Drainage Act gives power to the Engineer to enter on land (pending the usual action under the Land Acquisition Act) and commence work in certain special cases, namely, where an existing channel or embankment is threatened with damage (e.g., from river erosion) or where a new head has to be dug for a canal which is actually flowing and irrigating crops. This last operation is rarely performed, heads being dug when the canals are dry.

Crops, trees, etc., which have to be destroyed, can be paid for by private arrangement with the owners. A large amount of trouble and expense can be saved by marking out land required for new works and also for re-modellings, improvements, strengthening banks and borrow-pits before crops are sown on it, and requesting the owners not to sow crops. This can be done as soon as orders on Preliminary Reports are received. The width of land required can be roughly estimated and a somewhat narrower strip marked out. When the detailed calculations are made, the marks can be shifted outwards.

Art 3.—*Work in the Summer.* Before a canal is opened the Revenue Subordinate in charge should inspect the canal and its branches from head to tail and see that all temporary aqueducts are removed and the banks made good and that any temporary bridges are either put in repair or removed from the channel.

* They should always be started during December. There are holidays from 24th December to 1st January inclusive. It makes a great difference whether the arrangements for starting a work are completed before the holidays or after them.

As soon as the canals are opened attention has to be given to the regulation of the supply and to its distribution, and to the watching and protecting of the banks. At the same time such works as can go on while the canals are flowing, namely the completion of the groynes and flood embankments and the strengthening of the canal banks, is continued. As soon as the high floods come, the work of watching and protecting the groynes and embankments demands close attention. When the floods subside and the canal supply runs low, particular attention has to be given to its distribution in order that standing crops may not suffer.

SECTION II.—PRELIMINARY REPORTS ON WORKS IN THE RIVER ZONE.

[This Section consists of an order issued about 1907 in the Derajat Circle of canals. The system has been tried for two or three years and found to answer well.]

Art. 4.—*Inconvenience of awaiting River Survey.* Proposals for canal heads, etc., are not sent in till after the river survey is finished and plotted. This procedure, in spite of every effort, often causes delays involving serious consequences. Floods, sickness, absence of men on leave or changes in the staff may cause delays in the completion of the surveys or in the preparation of reports. Owing to lines of channels, etc., not being fixed in time, crops are sown on the ground to be occupied, and these have to be destroyed and paid for. The acquisition of land is delayed. The earthwork is delayed and is perhaps only finished in time by giving extra rates. Owing to hurry and rush (themselves highly inconvenient to all concerned) the work may not be properly dressed and benches,* etc., not properly removed. Other defects in earthwork (towards the removal of which much attention is being given) may have to be passed over. Finally the opening of the canal may be delayed and loss of revenue results as well as hardship to the people.

Art. 5.—*Substitution of Sketch Map for Survey Map.* The Executive Engineer, Subdivisional Officer and Sub-Overseer should, during the floods, keep themselves acquainted (this they already do to a great extent) with the general state of the river channels near the head and with the working of the head and of any creeks near it. They should also take note of the state of affairs in any place where the river has come near to, or was already near to, any channel or embankment, even if there is no canal head in the vicinity. The final position assumed by the main stream is usually determined by the high floods. These are generally over on the Indus by the 10th or 12th August and on the Chenab and Sutlej by the 20th August.

During August the Subdivisional Officer should prepare, for each Sub-Overseer's section, a copy of the previous year's survey map of the river. Taking with him this map the Sub-Overseer should, not later than 1st September, inspect the river near the canal head, and should sketch on it in pencil the existing state of affairs. Anyone of ordinary intelligence can do this. He can ride up the bank and come back by boat. When in doubt as to the exact position of the main stream or other matter he can

* Transverse walls of earth left unexcavated to enable the work done to be accurately measured.

obtain information from the ferrymen and boatmen. If convenient, he can send the crew of the inspection boat to inspect the river before he goes himself. If no inspection boat is available a country boat can be hired.

Art. 6.—*Information to be given on Sketch Map.* The sketch should not extend to the far side of the main stream.

Sometimes a river (especially the Indus) divides into two streams of nearly equal size. The boatmen will usually be able to say which is the larger stream.

The sketch should cover the whole length of river affecting the canal heads. This length may, if there is only one head and no other is proposed, and if the main stream, or a large creek which will not run dry, flows near the head, perhaps be only two miles either way, but generally it will be more. If there are long or numerous creeks whose continuous flow is uncertain, the sketch may have to cover them all.

Sometimes the main stream may be far distant and there may be a network of creeks. In such a case the sketch would be difficult, but for the fact that many of the creeks will probably be in the same position as before.

Any places where erosion is going on should be shown by small arrows (Fig. 39) and mention of them made in the report with remarks as to the severity of the erosion and the probability of its continuance. Land which is high (*i.e.*, submerged only in high floods) should be marked "High" and land which is covered with jungle should be marked in the usual way.

The general depth of water in creeks should be observed at a few places, especially near their off-takes, and shown on the sketch with the dates of the observations. Readings of the canal gauge and of the nearest river gauge should be added, the dates being always given.

All names* of embankments, head channels, etc., should be entered and also letters illustrating the report.

If a Sub-Overseer is ill or absent the Sub-Divisional Officer must send another or prepare the sketch himself.

Art. 7 —*Sub-Divisional Officer's Report.* The Sub-divisional Officer should take the map from the Sub-Overseer, go over the ground with him, correct the sketch if necessary, and prepare a report containing proposals as to the canal heads. He should have prepared during August a tracing of the previous year's map for each canal head (or for a group of heads if near together and to be dealt with together) showing in the usual colours all embankments, canals, creeks, etc., which have not altered since the previous season. To this tracing he should transfer the sketch and so make a complete and clear sketch map. It will show only the existing state of affairs and not the previous seasons.

If at any place, whether near a canal head or not, the river has eroded its bank and threatens to cut into the canal, or into an embankment, or has

* Every head channel and every reach of embankment should, as soon as its construction is decided on, be given a name, generally that of a neighbouring village, and the names should always be shown on the maps and sketch maps.

actually cut into it, so that a diversion may have to be made, a sketch of this place should also be made and the Subdivisional Officer should include it in his report.

A note should be entered on the map stating what portions of it are sketches and by whom they were made and by whom checked, with the dates. This is necessary in order to prevent the sketch map being subsequently confused with the survey map which is eventually made.

The Subdivisional Officer should promptly send on the map to the Executive Engineer with his report. The report should be in tabular form, the headings of the columns being as follows :—

- | | |
|--|---|
| 1. Proposed line for Main Head. | } Reference to be given to names and letters on sketch map. |
| 2. Proposed line for Subsidiary Head. | |
| 3. Remarks by Sub-Divisional Officer. | |
| 4. Remarks by Executive Engineer. | |
| 5. Remarks by Superintending Engineer. | |

If the Subdivisional Officer should be prevented by illness or other cause from making his inspection and report at the proper time, the Executive Engineer should do it. The Executive Engineer should send on the papers to the Superintending Engineer with his recommendations. Each canal head (or at least each group of heads coming into one map) should be dealt with separately and submitted separately. Any head which seems likely to need new channels or heavy work should be given preference.

In the report nothing can be dealt with except the selection of lines, *i.e.*, what heads are to be retained and what new ones are needed. If attempts are made to go into questions of water levels or gradients delay is likely to occur, unless the levels happen to be known from the readings of gauges at or near the off-takes.

If a canal has no subsidiary head, proposals can be made for one if there is any suitable line. Information should be given as to the working of the head up to the time of reporting, the date of opening of the subsidiary head, if any, and the cutting or breaking of banks, flood embankments or groynes. Any heavy silting, falling in of canal banks, etc., should be mentioned.

Any proposed additions or alterations to flood embankments should be mentioned, and also to groynes or escapes, if convenient, though for these it is generally best to await the river survey. In cases where such alterations affect the question of a canal head or diversion they must be fully gone into.

The Chief Engineer has ruled that the Executive Engineer must inspect each head himself. When possible, the inspection should precede the submission of the report to the Superintending Engineer.*

* Inspection before the sketch map has been prepared is generally unsatisfactory. Owing to the long distances things cannot be seen in their proper proportions.

Art. 8.—*Dates of Submission of Reports.* The Subdivisional Officer's reports should begin to reach the Executive Engineer about the 5th September and should all reach him by the 15th September. The Executive Engineer's reports should reach the Superintending Engineer from 15th to 25th September. If a report on any case has to be sent to the Chief Engineer it should reach him by the 1st October. Cases may occur in which the inspections are delayed a few days owing to a late flood. In such cases special arrangements should be made to expedite the reports. The Subdivisional Officer can accompany the Sub-Overseer or go the next day and the reports, etc., can be sent by special messenger or unofficially and the delays of routine procedure avoided.

The canals noted below are somewhat remote and work on them is seldom heavy and the dates for inspections and submission of report may be one month later than for other canals.

<i>Division.</i>				<i>Canal.</i>
Multan	...	...	...	Sikanderwah.
Muzuffargarh	...	...	...	Karm.
Dera Ghazt Khan	...	...	...	Massuwah.

Art. 9.—*Remarks.* The Superintending Engineer may sometimes require further information before giving final orders. In some cases he may wish to have levels taken on alternate lines. Since the canal heads have to be got ready first, the Superintending Engineer will, whenever possible, give definite orders as to these. For embankments there is generally plenty of time, and in the case of an embankment threatened by erosion it may be suitable to wait till the following April (in order to see whether erosion recurs), but not if the work is likely to be heavy.

When the Superintending Engineer issues his orders he will return the sketch map and report to the Executive Engineer. The sketch map and report may sometimes include more than one canal. When any further reference is made by the Executive Engineer a tracing from the plan (sufficient only to show the particular heads concerned) and an extract from the report should accompany it. All references will thus be intelligible. Matters between the Executive Engineer and the Subdivisional Officer should be similarly arranged.

A high flood may now and then occur in September. Such a flood may or may not alter the position of the river channels. If it does so the sketch and report may have to be done again. This will not often happen and the risk can be taken. It may also sometimes happen, especially where there is a network of creeks, that a preliminary report will not enable the arrangements for a head to be decided on and a survey must be awaited. Any such survey should be made with the least possible delay. Such cases will not be common and even when they occur, something will have been gained by considering the question beforehand.

As soon as orders on the Preliminary Report are received the sites of all the dams to be made at canal off-takes (Chapter II., Arts. 19 and 20) should be shown on the sketch plan.

SECTION III.—DETAILED PROPOSALS FOR THE SEASON'S WORK.

Art. 10.—*Levels or Silt Clearances.* As soon as orders on the preliminary proposals for canal heads are given by the Superintending Engineer, the lines should be levelled with the least possible delay, preference being given to those with the heaviest work or in which land will be required, or, if any such case occurs, in which the orders of the Chief Engineer have to be obtained. In the meantime those reaches of the canals and branches in which silt clearance is likely to be required, should be levelled. Such reaches are roughly known from the experience of former years. To level all channels from head to tail is not only a great waste of time, but it delays the submission of the estimates and throws back all the season's work. The levels should be begun directly the canals cease to flow. Excuses made by subordinates to the effect that the channel is not dry, should be anticipated and dealt with beforehand. Some portions, especially in branches, become dry at once and others can be drained. In all cases the bed level observed should be, as nearly as possible, the mean bed level across the whole width to be cleared, see Fig. 40. No "side silt" should be separately measured.*

Sometimes silt clearance sections are submitted which turn out to be wrong. Occasionally the improbability of their being right is apparent. In such cases checks (besides the usual one of recording the starting and closing Bench Marks on the sections) should be made before they are sent up.

Art. 11.—*Longitudinal Sections.* The longitudinal section of the head reach of each canal should extend downstream as far as the silt is believed to extend and should be accompanied by the longitudinal section of any subsidiary head which is to be cleared or constructed. Each longitudinal section should be carefully lettered to correspond with letters on the river plan, a letter being always entered at each off-take and junction. These sections will probably cover the heaviest work on the canal and should be sent in, canal by canal, at the earliest possible dates.

The R. L. of the water surface of the river, at each off-take, with the date, should be shown, and also the probable lowest water level. If the section is taken, say, on 15th October, the reading on the nearest river gauge on 15th October of the previous year should be seen and also the lowest reading of that season, probably in December, January or February. The difference gives the probable fall after the 15th October and thus the probable lowest water level of the current year can be found.

If the canal takes off from a creek which is dry, or likely to go dry, the bed level of the creek should be observed and shown. If the creek is dry by, say, 30th September, in a year in which the river is not abnormally low, the levels must be continued up the creek to the river or to flowing water, or, if the creek is very long, its upper part alone may be levelled. In such a case the real off-take is the creek off-take.

* See Chap. II., Art. 2.

For the rest of the canal the longitudinal section of the main canal and of the branches, should if possible (but not if this will delay any heavy work) be sent in all together. On the longitudinal section of a branch the actual F. S. Level of the main canal, at the branch off-take, should be shown and also the chainage of the off-take.

In all cases the proposed bed should be shown by a firm red line. Generally the proposed bed level should be somewhere about the lowest water level of the river at the off-take. The cleared bed of the previous year, if different from that now proposed, should be shown in dotted red ; if the same, this should be noted. The proposed bed widths should be noted and also the existing widths or (in creeks, etc.) the last year's widths.

Art. 12.—*Levels for strengthening of Banks.* The strengthening of banks is a matter which can be seen to at other times and independently of the winter clearances,* but generally labour is most plentiful in winter. If any bank strengthening is necessary in reaches where silt clearance is to be done, the bank level should, if there is time, be observed at the same time as the bed level, and should be shown on the longitudinal section, the right by a full line and the left by a dotted line. The proposed top of bank should be shown by a red line. Cross-sections should not usually be observed at this stage, because of the delay involved, except perhaps a few as types.

Art. 13.—*Preliminary Estimate.* In all cases the attached form should be filled in and submitted. The starting of clearance or other urgent work in anticipation of sanction to a formal estimate is nothing new and is, of course, necessary, and is permitted by the Public Works Code, but the filling in of the form enables the Superintending Engineer to see to what he is being committed and to check any tendency to increase of the rates.

In every case it should be stated whether the canal is Early, Ordinary or Late (Chapter II., Art. 1), and brief remarks should be given dealing with the general sufficiency of the supply and the possibility (or otherwise) of increasing its irrigation. It will then be possible to judge whether the bed at the off-take should be dug below or above the probable low water level of the river and whether the width proposed is suitable.

Owing to the frequent changing of canal heads, large schemes for permanent remodellings and improvements of canals are generally confined to the reaches downstream of the head reach. The detailed annual proposals for heads should therefore include any improvements which seem desirable in any head reach which is to be retained and used.

Any length of channel in which the depth of silt to be cleared is small, say 50 foot in a large channel and 40 foot in a small one, should not be cleared, provided its length is considerable (say 1,000 feet) and that it is not close to (say within 3,000 or 2,000 feet from) the head of the canal or branch. Estimates should be prepared accordingly, the shallow digging being struck out. Clearing a small depth of silt merely gives contractors a chance of cheating by scraping the bed.

* See Chap. II., Art. 1.

Work to be Begun in Anticipation of Formal Sanction.

1. Name of Work_____
2. Head to which chargeable_____
3. Locality. Form R. D._____
- To R. D._____

Estimate Rates.

Last Season_____

This Season_____

Remarks_____

Rough forecast of quantity of work.

Probable date of submission of estimate.

Specification.

Kind of work.	Reference to specification.	

SECTION IV.—RIVER SURVEY.

Art. 14—*General Description.* Besides any special survey required for canal heads (Art. 9), surveys are necessary in order that there may be correct maps on which to base next year's sketches. Surveys are necessary for the whole of the Dera Ghazi Khan Division, except the Massuwah, because proposals for groynes are every year submitted to the Chief Engineer.* During October and November the staff are occupied in levelling, etc., for canal clearances. The river survey should be made and plotted in December. Correct maps can thus be prepared in time for proposals for flood embankments or escapes. If necessary, special men should be employed to assist the permanent staff. The survey should be plotted to a scale of 2 inches to a mile, 4 inches has been found to be needlessly large.

* The latest date for this is 1st February, but any cases involving closures of flowing streams should be sent up in December.

The surveys are generally inaccurate or defective. The roads, channels, embankments, etc., shown on the maps supplied to the surveyor, may not be accurate. A correct map of all such features of the river zone is necessary. Again the features do not always extend far enough inland and may be cut away by the river. If this occurs it may be impossible, some years later, to properly compare the survey with a recent one. Where there are canals, etc., on both sides of a river, the two surveys are generally made quite independently of one another. This is right, but the features of the two zones should be connected once for all and a map showing them all kept up by the Superintending Engineer, at least on the Indus where questions of the movement of the stream are likely to continue to occupy attention.

Art. 15.—*Method and Extent of Survey.* On some occasions the system adopted has been bad. In some places there are permanent masonry pillars. These, in order to be safe from erosion, are so far from the river as to be useless. On many occasions embankments and channels which have not altered for many years, have been surveyed afresh every year. Sometimes the position of the river bank has been found by running from an embankment or channel long off-set lines of such a number that their aggregate length far exceeded that of the portion of the river bank concerned. The proper arrangement is to supply the surveyor with a tracing showing all the features of the country which have not altered since last year, and for the surveyor to survey by chain and compass whatever has altered. The surveyor need seldom cross the main stream. He can of course take cross bearings to flags on its further bank.

The survey should show both banks of the main stream and all creeks, sand-banks, etc., on the near side of the main stream. Where there is a long stretch of river without any canal head, no survey of it need be made, unless the preliminary report has shown that the stream is getting dangerously near to a channel or embankment. The survey of each canal or group of canals should cover all the ground covered by the sketch or sketches (Art. 6), unless some alteration seems desirable. It should give similar information to that given in the sketches.

APPENDIX A.

THE MOST SUITABLE DATES FOR OPENING INUNDATION CHANNELS.

1. *Time when the demand begins.*—The demand for water may begin as early as 16th April, for small areas under sugar-cane or old indigo, or it may begin about 25th April for indigo, vegetables and cotton. Generally it begins about 6th May. If there is no indigo, vegetables or cotton, the demand may not begin till 15th May or even 1st June. By "demand" is meant appreciable demand. A demand for water for a few seed-plots, which can easily be watered from wells, may of course occur at earlier dates. If the weather is unusually cool the *rabi* harvest may be delayed and this puts back the demand, as also does an unusually heavy *rabi*, because the people have no land or time to spare for sowing *kharif* crops. If the *rabi* is both late and heavy, the demand may be put back for weeks.

2. *Reasons for and against immediate compliance with the demand.* There are some objections to opening a canal the moment an appreciable demand begins. Early opening may, owing to the small demand, give rise to breaches and damage to property, or it may, owing to the small depth of water, if the river is low, give rise to silt deposit in the canal head. Even if the canal, as is now usual, has a flood regulator and escape, this may not help matters much. If only a small supply is passed down the canal it may be of little use for irrigation because, though the volume of water may suffice, the depth may not be enough to command the fields except towards the tail of the canal. Also the bed of the escape is generally three or four feet above that of the canal and the escape will probably not work until the water in the canal is headed up, and this will probably cause a serious deposit of silt. If a canal has branches which flow in turns, they cannot perhaps all get water at first, and this may be a reason for somewhat expediting the opening. The questions of breaches and silting will now be further considered.

3. *Breaches.*—There is generally some jungle land on to which waste water may be run through water-courses, and breaches thus reduced, but in spite of this the opening of a canal when the demand is small may cause serious breaches, especially towards the tail. The damage to the banks may be considerable. Roads may be flooded and traffic on them stopped. If wheat, which has been harvested and stacked, is submerged, the damage done may be extremely heavy.

4. *Silting.*—The quantity of silt in the river water early in the irrigating season is not so great as in the flood season, but it is quite enough to cause silting of canals if run with low supplies. Kennedy's diagrams show that the tendency to silt with depths of water of only two or three feet is great. With a depth of one foot the tendency is still greater. In some canals silt always deposits early in the season and it remains there all the season. Though the deposit may affect the supply only slightly in high floods, it affects it greatly in the intervals between the

floods and most of all at the close of the season when it finally cuts off the supply as the river falls. The point for consideration is whether, in any particular canal, silt deposit with low supplies will occur and will remain. This can be settled by the experience of previous years or by having regard to the section and gradient of the channel. It is most likely to occur with small sections and flat gradients. It generally occurs to some extent. If it occurs, then the earlier a canal is opened the earlier it will go dry. Early drying is far worse than late opening. It of course causes more or less failure of standing crops.

5. *Decision as to date of opening.*—The tendency to silting being greater as the depth of water is less, it is clear that the lower the river the greater the need for postponing the opening of the canal. But as the season advances, the less will be the depth of water with which it will be legitimate to open, not only because there is an increasing chance of a rapid rise in the river occurring after opening, but also because of the increasing hindrance to irrigation which will occur by keeping the canal closed. In the week or ten days immediately succeeding the first demand, the hindrance will be comparatively small, because only one or two kinds of crops will be affected, but later on more crops will be affected. Generally speaking, with a depth of 3 feet in the canal head there will not be much danger of silting. Supposing this to be the case, then if a depth of 3 feet is available there is no objection to opening, on the ground of silting alone, as soon as an appreciable demand has sprung up. After a week the above will be true for a depth of $2\frac{1}{2}$ feet and after another week for a depth of 2 feet. On certain large and straight canals in the Lower Sutlej Division where little silt deposits, few breaches occur, much indigo is grown, and there are branches flowing in turns, it is found advisable to open about a month earlier than on other canals.

5. *Remarks.*—The people and the Civil Officers sometimes complain that the canals are not open soon enough. Occasionally a delay has occurred, at times when there have been labour difficulties, because of the non-completion of some works, but generally any deferred openings have been proper and have been due to the causes stated above. The people undoubtedly like to have the canals opened too early. They think only of the present, know nothing about the height of the river, and reck nothing of early drying of the canal or of breaches. The Executive Engineer is the only person who can form a proper judgment.

In old times the canals were undoubtedly opened too early. Some used to be opened in order to irrigate a few seed-plots or even for the convenience of those attending certain “melas,”* the water often breaking out and stopping traffic on the district roads.

* Fairs.

APPENDIX B.

SPECIFICATION FOR BUSHING.

1. The branches to be large, leafy and freshly cut. To be laid so as to be almost entirely submerged. To be closely packed together. As the branches become weighted with silt (some of the leaves also drop off) they settle down, and more must be added.

2. Bushing is generally begun soon after the canals open and while the supply is rather low. As the supply rises more bushes are added. Thus the whole operation of bushing a length of canal may extend over several weeks.

3. If leafy branches are scarce, others (*e.g.*, those of the *kikar* or *Acacia Arabica*) can be used, but not by themselves. They can conveniently be used when it is necessary to commence bushing before the canal is opened.

4. Branches to be obtained, as far as possible, from Government trees. If the trees are intended to remain, the branches must be cut with judgment. If the trees are on the berms or in other unsuitable places all the branches may be cut off, but the trunks may remain as a temporary arrangement so that fresh branches may be available.

APPENDIX C.

REMODODELLING OF INUNDATION CANALS.

I.—EFFECT OF BENDS.

1. *Effect on Velocity and Silting.*—Bends, if not very sharp, are believed to have little effect on the velocity of a stream and they probably do little harm even if numerous. Sharp bends, if numerous, have the effect of increasing N in Kutter's co-efficient or (what is the same thing) in reducing the velocity and increasing the tendency to silt. In the head reach of a canal where silt generally deposits, sharp bends, like anything else which increases such deposit, are highly objectionable. In the lower reaches where silt does not deposit, such bends do little or no harm so far as silt is concerned.

2. *Other Effects.*—The bank at a sharp bend is liable to fall in, especially in a large stream and in light soil, and this may be a serious evil. Again, a channel with numerous sharp bends cannot be made to look neat, and this is likely to prevent officers from taking a proper interest in its maintenance. This consideration is of more importance than might at first appear. Lastly, a succession of bends even if not sharp, may cause a large "loop" in a canal and considerably increase its length.

II.—STRAIGHTENINGS.

3. *Object.*—The object of straightening is—

(a) To remove sharp bends.

(b) To reduce the length of channel and so improve the command or the gradient.

4. *General Principles.*—The most suitable arrangement for each case is a matter of judgment, but a few general rules can be given. Sometimes it is desirable merely to effect an "easing off" of a corner (Fig. 41). Sometimes to make a "cut-off" (Figs. 42 and 43) which runs outside the existing channel. Sometimes a long cut can be made to get rid of a number of bends. Too severe straightenings should not be effected. Many curves, not too sharp, must remain. The minimum radius of a curve should be about five times the bed width. It is best to keep to the existing centre line where possible as in $a b, c d$ (Fig. 41). If the line shown in Fig. 44 is adopted, there is great cutting away at one bank and filling at the other with little gain. Much, however, depends on whether a channel will be in embankment or not. If in much embankment the cost of adopting a new or straightened line may be no more than that of adhering to the old line because the cost of embanking the channel will be heavy.

5. *Large Scale Plans.*—A plan (scale 1/1000 for channels whose bed width is 20 feet or more and 1/500 for small channels) should be made of all parts of the canal excepting those which are quite straight or in a regular curve. The plans should show bed and banks and the boundaries of Government land. No straightening should ever be effected without a plan. A specimen plan is given below. (Fig. 47).

The proposed alterations can be sketched in pencil and a sub-overseer or draftsman can complete them with rule and compasses for final approval. Attempts should not be made to make a certain standard radius, say 500 feet or 100 feet, fit in. The radius adopted should be whatever will fit best. If one circular arc is not suitable a compound curve (Fig. 45) can be adopted.

A Sub-Overseer or Surveyor if merely told to make a large scale plan will nearly always make it wrong. See circular No. 11,* paras. 14 and 15. If the teaching therein enjoined is neglected immense trouble is likely to occur and the plans will probably have to be made twice.

III.—CROSS-SECTION.

6. *Filling in of parts of Channel.*—The hatches on the plan (Fig. 47) show where filling in has to be effected; it has also to be effected in places where the channel is too wide even if not crooked. Bushing requires some time to produce a good result, and should therefore always be done early in the flowing season. With the aid of the large scale plans, it can easily be seen where bushing is needed, and this part of the work should be done as early as possible. Otherwise when the earthwork is done great trouble will be experienced, and the work will be left in an unfinished state for want of the berms. For instance, if the designed bank is *fb* (Fig. 46) the portion *ab* cannot be made till *cde* has been formed.

If remodelling of banks has to be done before *cd* has been formed the part *fa* should be made and *ab* added afterwards.

7. *Type sections aimed at and obtained.*—A definite cross-section for each reach will, no doubt, form part of the design. Boundary roads and plantation water courses may or may not be required. It may not be possible without great expense to bring the bed width to absolute uniformity. Some reaches may have to remain somewhat too wide. Also the banks cannot generally be brought quite parallel to the channel. The berm may be allowed to vary gradually in width.

IV.—WATERCOURSES, ETC.

8. *Jhalar*s.—All jhalars† on canal land should be removed. Frequently the remodelling gives flow irrigation. If the jhalar is required at all, it should be placed on a neighbouring water-course, or, if no such water-course exists, placed outside canal land and an outlet made for it. This will be done at Government expense. Often 2 or 3 jhalars can be combined.

9. *Well Crossings.*—In remodelled channels temporary aqueducts should not be allowed. Syphons may be required or else wells sunk at the cost of Government. All well crossings should be shown on the large scale plan or (in the straight cuts) on the land plans.

V.—MARKING OUT.

10. *Bed Blocks.*—These get displaced by scour in large canals, and become a source of trouble. They are not generally necessary.

* This refers to Derajat Circle Order No. 11.

† A jhalar is a Persian wheel.

11. *Centre Line, etc.*—The centre line of the channel should be marked by large pegs standing up 3" to 6" above the bed so that the line can always be found again. A peg is required at the beginning and end of each curve and intermediate ones at short intervals in the curves. Opposite each peg two stakes should be driven, one on each bank, equidistant from the centre line peg. Thus the centre line can be found even when the canal is flowing.

VI.—JUNGLE AND TREES.

12. *Jungle and Trees.*—These will probably be much needed for bushing and they sometimes become extremely scarce. No clearance, thinning or cutting should be effected on channels to be remodelled, or on others near them, until this point has been considered. The top portions of date trees make good bushing. When it is certain that they will not be required for bushing, etc., all trees, etc., should, as a rule, be cleared from the inner slopes and tops of banks.

13. *Inside Jungle.*—This may be most useful, forming a sort of natural bushing, and should in many cases not be cleared. If the canal silts and becomes narrow, it is easy to cut and trim it. It is extremely difficult to narrow it if too wide.

VII.—MISCELLANEOUS.

14. *Old Loops.*—When a loop has been cut off and silting operations (if any) have been finished,* the banks at both ends should be levelled down. This should be done within the area of the Government land which is still to be retained, and a little more, so as to leave space for boundary marks, etc. The land under the abandoned loop should be surrendered.

15. *Old Water Courses, etc.*—When these are abandoned (the head portions at least should be abandoned if their banks are high) all the portions within canal land should be levelled down, and the part just outside.

16. *Old Ring Banks, etc.*—These will of course be removed, and the bank made straight.

* When a loop is to be silted up the upper end should be strongly closed, the bank being made up in proper line. The lower end can be left open (unless its banks are too weak) and silt will deposit in it. After a year or two the upper end can be opened by making a narrow staked opening. The loop will now (unless very long) probably all receive silt deposit because of the obstruction in the lower end and both ends can be finally closed by banks in the proper line.

APPENDIX D.

WARNINGS OF FLOODS.

1. Reading of gauges in the upper reaches of the Punjab rivers are registered in order that it may be seen, by comparison, what rises and falls are likely to occur in the lower reaches. By studying the entries and marking off the highest readings in pencil it is easy to see how long floods take in coming down. To see what height the floods are likely to attain is not so easy. The height of a flood in the lower reaches depends not only on the height of the flood in the upper reaches but on its duration.

2. On the Chenab the floods are generally short and sharp. They attain their maximum height when (as often happens) there are simultaneous floods in the Jhelum, Chenab and Ravi. The Sub-Divisional Officer, Chenab Sub-Division, Multan Division (Lala Makhan Lal) by noting the above gauges predicted in 1903 an exceptional flood which shortly occurred and all in the Multan Division were ready for it. In the Muzaffargarh Division disaster occurred.

3. Telegrams indicating sudden rises on the upper gauges are regularly despatched. If received only in the Divisional Office they should be at once communicated to Sub-Divisional Officers. Wherever there is a Telegraph office at the Sub-Divisional Officer's headquarters the telegram should be sent to him as well as to the Divisional Officer direct from the despatching station. The Sub-Divisional Officer should communicate the telegram promptly to such subordinates as he thinks necessary.

4. Every such telegram should show the gauge reading, the time of the reading and whether water is rising, steady or falling. When a telegram is received the reading should be entered as below, between the lines, so as to leave room for the readings subsequently received by post.

Date.	Shahdara.
1	
2	
3	6.5
4	

APPENDIX E.

WATCHING AND PROTECTING BANKS AND EMBANKMENTS.

1. *Watching*.—Every watchman employed to have a fixed headquarters and a fixed beat. If there is no permanent hut on or near the bank, grass huts should be erected by the men at the places fixed. The presence or absence of the men to be frequently tested by the mate and Sub-Overseer. The Sub-Overseer's tests to be recorded in a book and to form the subject of frequent enquiry by the Sub-Divisional Officer, who will also record his remarks and take proper action in case the Sub-Overseer is in fault.

2. *Gauge Writers, Regulating Establishment, Bungalow Watchmen, etc.*—To be made to assist whenever possible. The allotment of a beat to each such man has been separately ordered.

3. *Employment of men on Repairs*.—The men when not otherwise occupied to do petty repairs, etc., within their beats but not to be put on miscellaneous duties and sent about as messengers, nor to act as orderlies or khalassies.

4. *Strength of Establishment*.—Should generally be greater for 1½ months in July and August than at other times. Care to be taken as to this and as to dismissing men when no longer needed.

5. *Stakes and Mallets*.—To be collected beforehand, if necessary, at suitable places, to be accounted for at end of flow season, and balance taken care of.

6. *Breaches*.—The establishment to be trained by the Sub-Divisional Officer to report every breach to all officials with the greatest possible speed. The mate, daroga and sub-overseer to remain there till the breach is closed and to promptly send a report on the prescribed form to the Sub-Divisional Officer.

7. *Serious Breaches*.—In case of serious breaches of main channels the Sub-Divisional Officer himself to reach the spot as soon as possible.

8. *Breach Reports*.—See printed form attached.* To be promptly submitted for each breach to the Executive Engineer. The report contains a column for cost of closure. This means the stoppage of the flow, and not the complete making up of the banks. The column for remarks of the Executive Engineer should be filled in and the report promptly returned to the Sub-Divisional Officer who will, in the meantime, be making up the banks and preparing a requisition or estimate.

9. *Progress Report*.—With the Executive Engineer's monthly progress report a list of breaches will be submitted, canal by canal, with columns showing date of occurrence and cost of closure. The return

* See Form M.

should be on the attached form.* The Sub-Divisional Officer should also submit this form to the Executive Engineer.

10. *Estimates.*—The cost of breaches is not to be charged to maintenance estimates. At the close of each month the Executive Engineer should submit or sanction an estimate, accompanied by the breach reports, for closing any breaches which have occurred and making up the banks.

11. *Breaches in the flooded area near Canal Heads.*—These may be of special importance. It may be impossible to do any good and money may be uselessly spent. In any such cases the Sub-Divisional Officer should at once proceed to the spot and the case should be reported by wire to the Executive Engineer and, if necessary, to the Superintending Engineer.

12. *Breaches in flood embankments.*—The Sub Divisional Officer must at once proceed to the spot and the case be reported by wire to the Executive Engineer and Superintending Engineer. The Breach Report forms can be submitted partially filled in at the earliest possible moment and a complete form afterwards.

* See Form G. This differs slightly from a form prescribed by the Chief Engineer for general use in the Province.

REPORT OF BREACH.

Form M.

Canal.	Branch.	Side.	Mile and Chainage & name of village.	Time of occurrence.	Time at which report reached Sub-Overseer and Darogha.	Time at which Sub-Overseer and Darogha reached the place.	Time at which flow of water was stopped.	Cause of breach.	Width of breach at time of closure.	Comments of Sub-Divisional Officer on the preceding entries.	Cost of closure of breach and of making up the banks.	Report and order of Executive Engineer.
1	2	3	4	5	6	7	8	9	10	10	11	13

Form G.

Return of Breaches in

Division
Canal during month of
191

(to accompany Divisional Narrative Progress Report).

NOTE.—This form can be extended with blank paper, if necessary. It should be submitted whether there have been breaches or not.

Annual serial No. of breach in Division.	Annual serial No. of breach in Sub-Division.	Annual serial No. on channel.	POSITION OF BREACH.			Date of Breach.	Cost of repairs, i.e., of stoppage of flow.	Date of receipt by Executive Engineer of detailed "breach report" on printed form.	Cause of breach and remarks by Divisional Officer.
			Channel.	Chainage.	Bank.				
1	2	3	4	5	6	7	8	9	10

APPENDIX F.

PRECAUTIONS AGAINST DELAYS IN IMPORTANT WORKS.

1. For any work on which the opening of a main canal depends and for any important groyne or flood embankment, which has to be completed in a short period, a register should be kept by Executive Engineer, showing the number of men employed, and should be seen by Executive Engineer daily. This will enable Executive Engineer to detect any want of progress and take needful action sooner than can be done by a mere perusal of a monthly Progress Report. This plan has always had to be adopted in Inundation Canal Divisions.

2. Whenever there is any sign of delay in any work of the above classes, the accompanying form* should be filled in and sent to Superintending Engineer, and its submission repeated every 10 days, until it is stopped by Superintending Engineer or becomes unnecessary. It will usually be returned to Executive Engineer at once and can be resubmitted after adding a fresh line and so on. If it is not received back in time a fresh form must be sent.

3. For smaller works careful scrutiny of monthly progress reports may suffice, together with prompt action on the part of the Executive Engineer when he sees any delay. If serious delay occurs the procedure laid down in para. 2 should be adopted. In all cases whatever the Executive Engineer is responsible for taking proper action to get works finished in time.

* Dera'at Circle, Form H. The first 7 columns show the progress to date, and the progress per man per day. The next 6 columns show the time still available, the work to be done and the number of men required per day. The last 4 columns show the number of men actually employed, and the arrangements made for increasing them.

APPENDIX G.

GAUGES IN SHIFTING RIVERS.

[The following is mainly an extract from the Roorkee Professional Papers, 1886.]

GAUGES IN SHIFTING RIVERS.

By E. S. Bellasis, Esq., Executive Engineer.

In a river whose course frequently changes there is considerable difficulty in obtaining a proper indication of the water-level by means of gauges. Many of the Indian rivers are of this class, and gauges have been established in them in order to obtain a record of the water-level and to keep the Engineers in charge of canals and embankments informed of the changes which are daily occurring. The readings of some gauges in the Indus are telegraphed daily during the flood season to Engineers in charge of works hundreds of miles down the river.

The chief difficulty arises from the fact that the water-level at any point in the channel is liable to vary abnormally, that is, independently of the quantity of water in the river or of the general water-level in the neighbourhood. (Chap. I. Art. 8.) It is clear, that the water-level in a creek is far more liable to abnormal variation than in the main stream. The average of the readings of several gauges in the main stream will generally correctly indicate the height of the river, but the average of the readings in creeks will generally be abnormally low.

It is also frequently necessary to move the gauge from one place to another. The stream may set against the bank where the gauge is placed, and keep cutting it away, or it may deposit silt so that the gauge is left dry when the river falls, or floods may render the gauge inaccessible; and sometimes the nearest available site for the gauge is a mile or two from the original site. The difficulty arising from the moving of the gauge is not, however, so great as might appear. The actual water-levels at different times are of course comparable only when observed at the same spot or on the same transverse section, but for most ordinary purposes, such as comparison of the height of the river in different months or years, or for informing engineers at a distance of the changes which are occurring, it is sufficient to consider the gauge readings only, without reference to the zero-level of the gauge or the actual level of the water. When the gauge is moved to a new site its zero is placed at a different level, so that the reading at the time it is moved is the same as at the original site, and the readings at the two sites are therefore comparable. As soon as circumstances permit the gauge is taken back to its original site, and its zero placed at the original level. When this is done there is often a sudden change in the reading because the difference in the water-levels at the two sites is not the same as it was on the day the gauge was first moved, but this

change is merely a proof that the water-level at one or both of the sites has been varying independently of the general water-level of the river. Even if it is desired to obtain a continuous record of the water-level at one place the moving of the gauge does not cause very much difficulty, because the water-level at the original site can be inferred by assuming that the reading of the gauge there would have been the same as at the temporary site. Any difference will be due to abnormal variation, and this is just as likely to occur at one site as at the other.

A few years ago the plan was tried of laying down a line at right angles to the general direction of the river and keeping the gauge always in that line with its zero always at a given level. This plan, however, was found to be very inconvenient in practice, and it possessed no special advantages. If erosion set in at one bank of the river it would sometimes be necessary to transfer the gauge to the opposite bank, whence the despatch of the readings to the Engineer would be attended with great difficulty and delay, and unless the stream happened to be running at right angles to the fixed line there would be a sudden change of reading when the gauge was moved across, and often a still greater change if it was moved into a creek. Keeping the gauge always in one line does not free it from the effects of abnormal variation of the water-level. The plan of moving the gauge to wherever a suitable site can be found is the only practicable one, but it is quite clear that the gauge ought always to be kept in the main stream, because the abnormal variation of the water-level there is likely to be less than in a creek, or—what is the same thing—the sudden change of reading when the gauge is brought back is likely to be less. It is better to move the gauge to a point 5 miles away in the main stream than to a point only a mile off in a creek. Even as a means of showing the daily changes of water-level for a brief period a gauge in a creek is unsatisfactory. If the sand-bar at the head of the creek is nearly dry a rise of 3 inches in the river may cause a rise of a foot in the creek. The object is to ascertain the water-level in the river, and the way to attain this object is to have the gauge in the river and not in another channel. There is, however, no objection to placing a gauge in a creek close to either of the points where it joins the main stream, as at these points the water-levels in the creek and main stream will be practically the same.

It is also evident that the mean reading of several gauges will generally vary abnormally to a very much less extent than the reading of one, and that the best way to ascertain the general water-level in any given locality is to have several gauges, say three. The zeros can conveniently be in a plane parallel to the average water surface. One gauge should be kept, whenever possible, in a fixed line at right angles to the general direction of the river, and the others a mile or two above and below. When moved the gauges should not be brought too near together, because then they would all be affected in the same way by any abnormal change. Neither should they be placed too far away from the fixed line, because the object is to register the water-level in one locality. A rise of 3 feet in one place might be accompanied by a rise of only 2 feet at a place 20 miles away.

The zero-level of the central gauge could be fixed at some round number, and the mean reading of all the gauges when added to this zero-level would give the water-level, freed to a large extent from abnormal variation.

The writer admits that in the flood season there would often be considerable difficulty in carrying out the above plan, but it would generally amount to no more than this that the gauges would be placed nearer together or further apart than would be quite desirable. It would always be possible to have several gauges, and the cost of reading them would probably be no greater than that of reading one. In winter, when the rivers are low, the gauges could all be read by the man who is at present employed to read one only. In the flood season if the gauges are too far apart to be read by one man, some of them could be read by the other men who are at this season employed to read the canal gauges.

E. S. B.

[The following is an extract from the Punjab Irrigation Branch Recent Orders as to River Gauges.]

4. When a river has a shifting channel the gauge site may be eroded or silted up and it may often be necessary to shift the gauge. In such cases a general map of the river should be prepared extending far enough to show all possible gauge sites and also the Bench Marks mentioned below. A cross line at right angles to the *general* direction of the river should be laid down on the map, and also on the ground by two masonry Bench Marks both on the same bank of the river as the gauge, and at a safe distance from its edge. The Reduced Levels of the Bench Marks should be carefully ascertained and checked by the Sub-Divisional Officer. As far as possible the gauge should be kept in this cross-line with its zero at the original level.

4A. If, however, the gauge has to be erected out of the cross line, its zero should be altered in such a way that it will (at the time of erection) read the same as if it were at the original site, or (supposing the original site to be silted up) as if it were in the cross line, at the nearest point to the original site where the main stream is flowing. Such a gauge may, owing to changes in the surface slope of the river, gradually come to give a reading different from what it would have given if in the cross line, and if the gauge is again shifted the error may be increased and eventually become large. For this reason, any gauge not in the cross line should be adjusted every year in October, its zero being re-set so as to make the gauge read the same as it would have read if in the cross line (at its original site or at the nearest point to it where the main stream is flowing), with its zero at the original level.

4B. If the gauge has ever to be placed in a side-channel or "creek" it should never be more than half-a-mile (measured along such side-channel) from the main stream.

4C. Whenever a gauge is shifted, the Reduced Level of its zero will be carefully observed and recorded. The Reduced Level of the zero of the original gauge will always be recorded. To avoid any chance of confusion from the record of reduced levels of the zeros of the original gauge and of that in use for the time being, separate lines are provided at the top of the register.

Fig 1

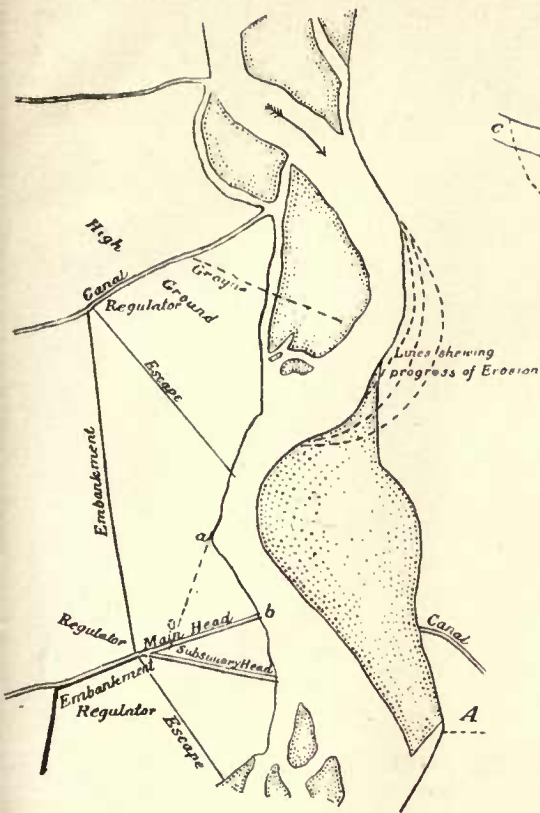


Fig. 2

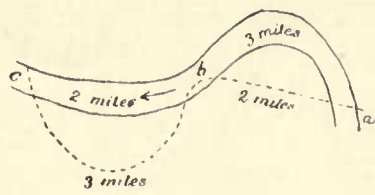


Fig 11

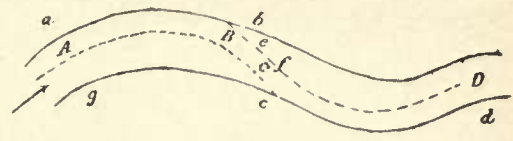


Fig 12

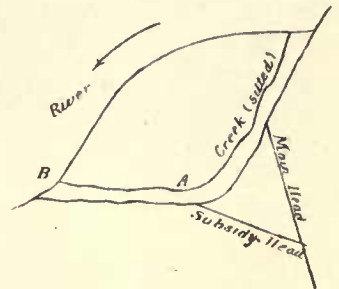


Fig 13

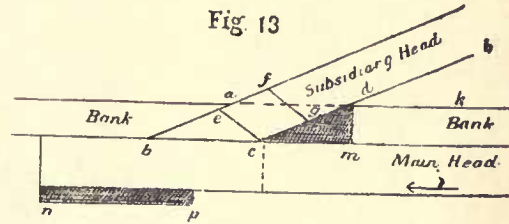


Fig 14



Fig 4

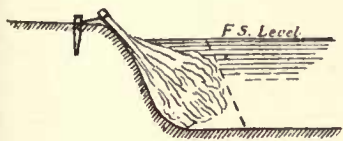


Fig 5

Fig 6

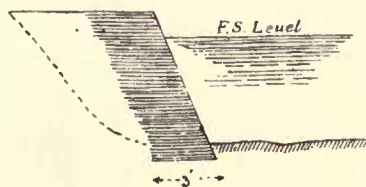


Fig 15

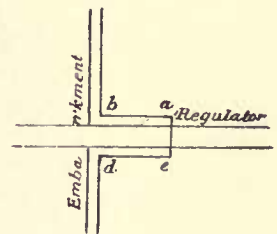


Fig 16

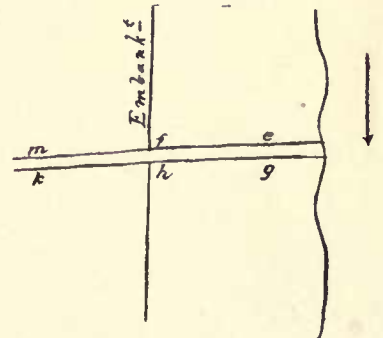


Fig 17

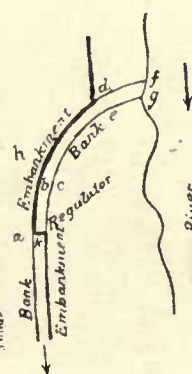


Fig 19

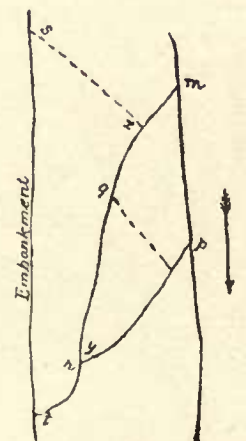


Fig 7

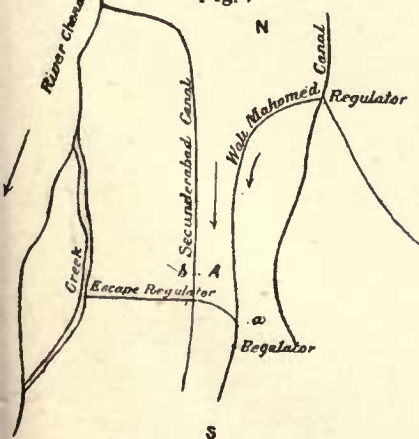


Fig 8

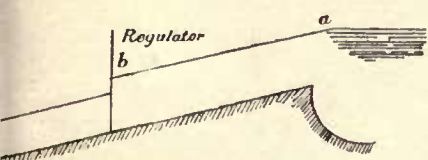


Fig 9

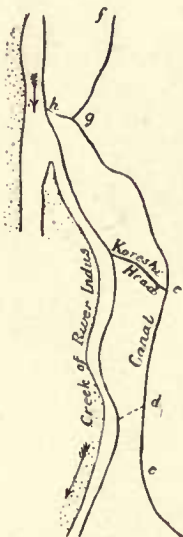


Fig 10

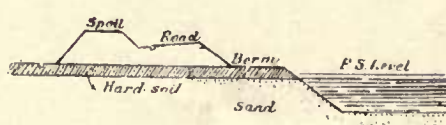
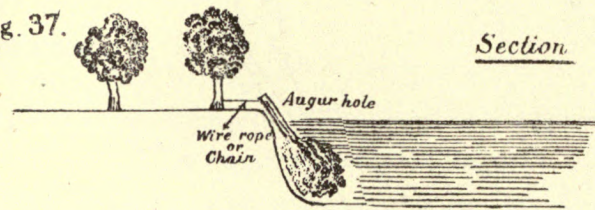
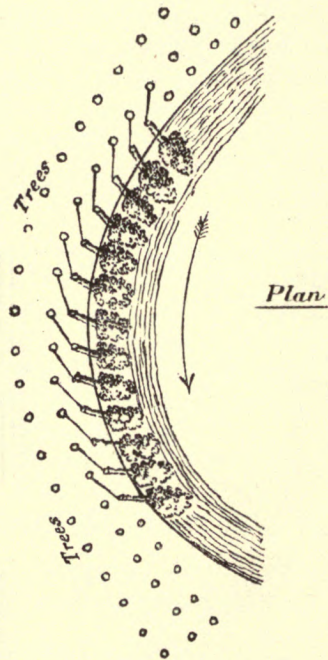


Fig. 37.



Section



Plan

Fig. 38



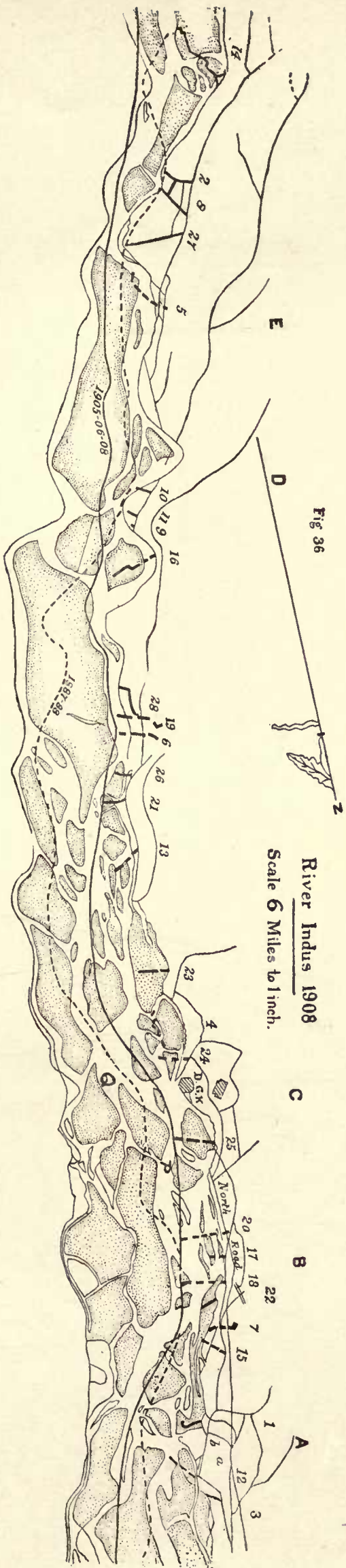
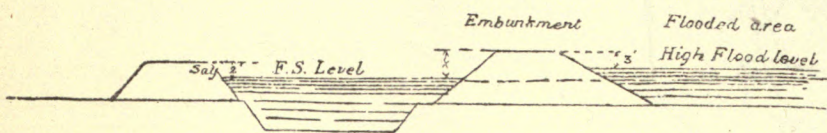


Fig. 18.



Height x may be perhaps 5', head regulator being assumed to be partly closed.

Fig. 22

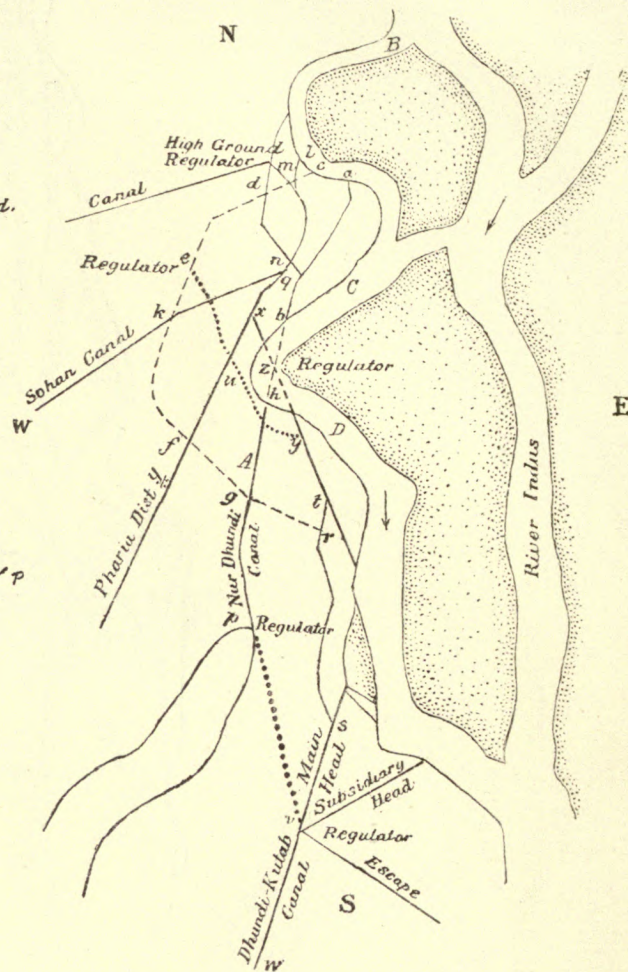


Fig. 21

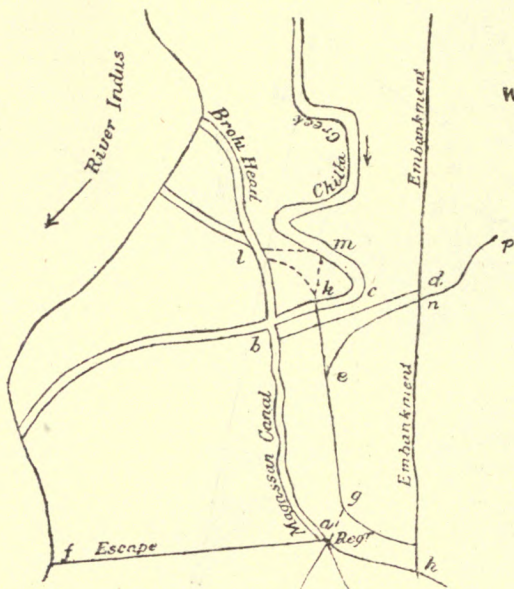


Fig. 20

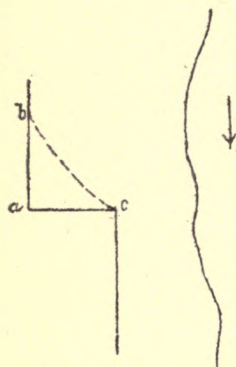


Fig. 23

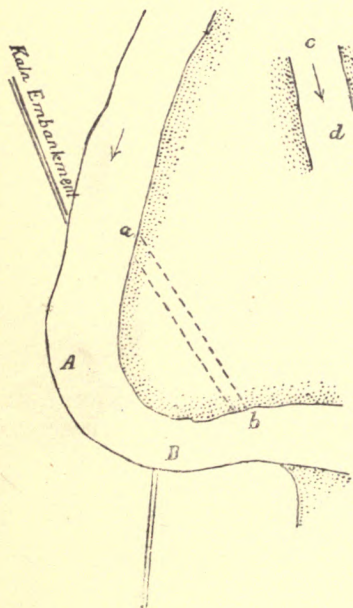


Fig. 24

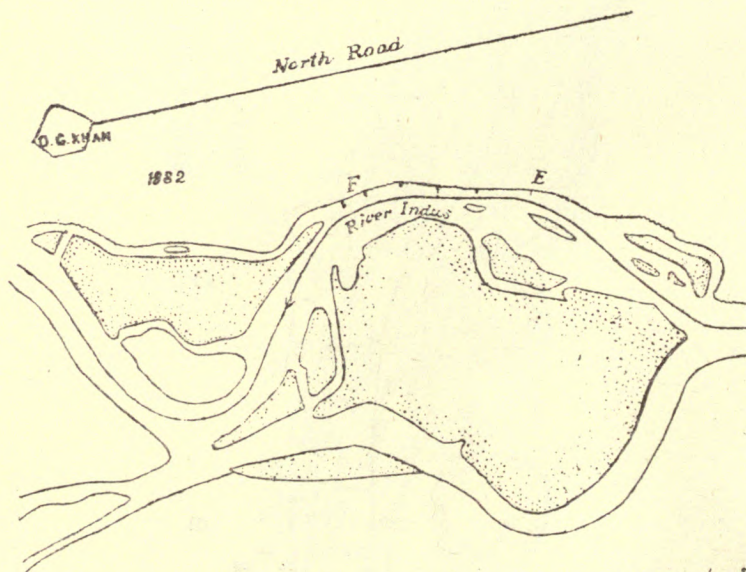


Fig. 25

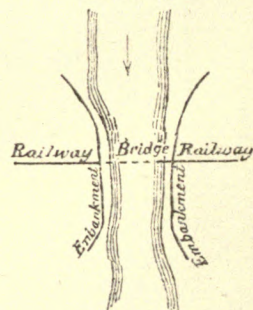
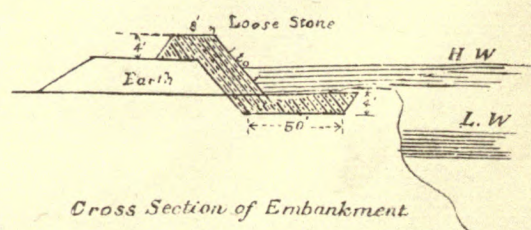


Fig. 26



Cross Section of Embankment

Fig. 27

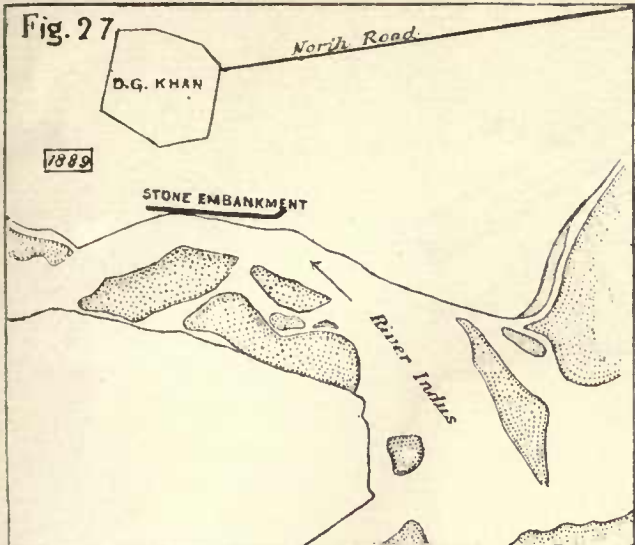


Fig. 31

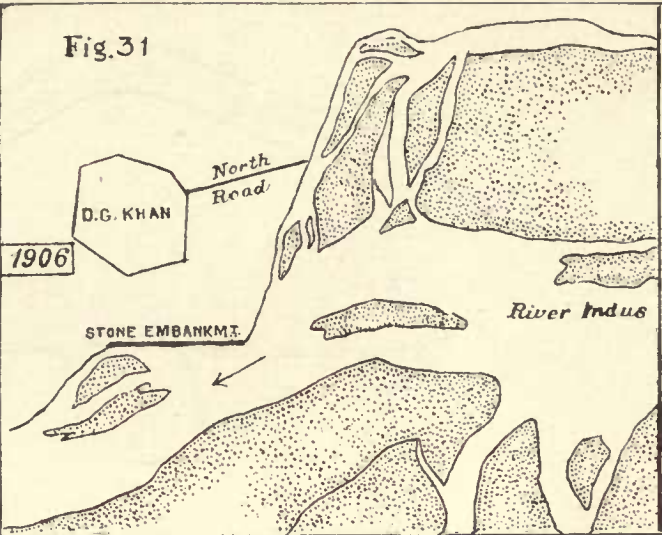


Fig. 35



Fig. 28

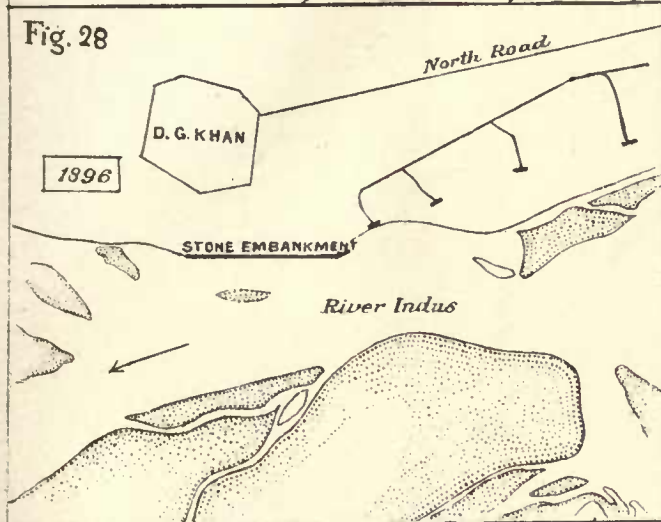


Fig. 32

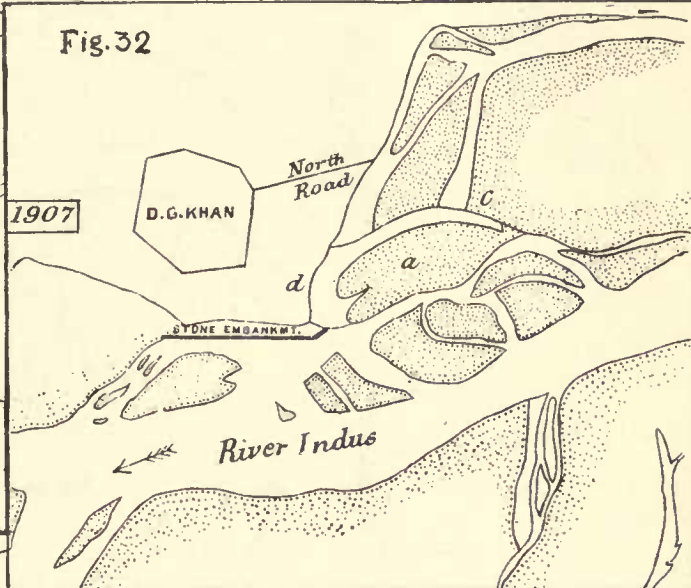


Fig. 29

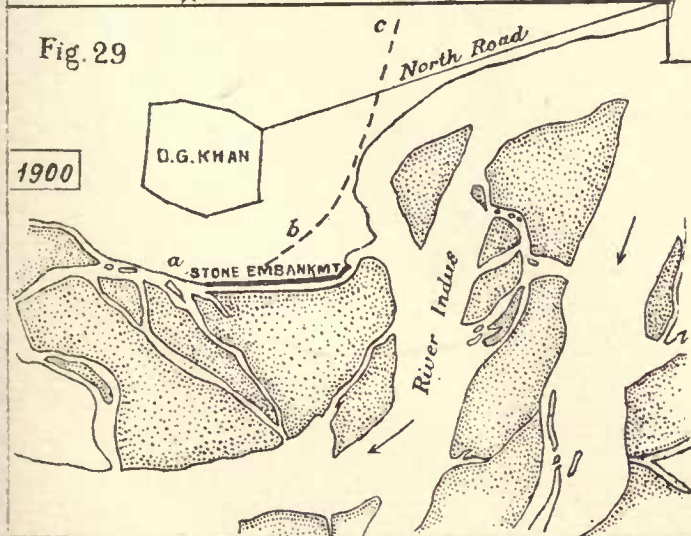


Fig. 33

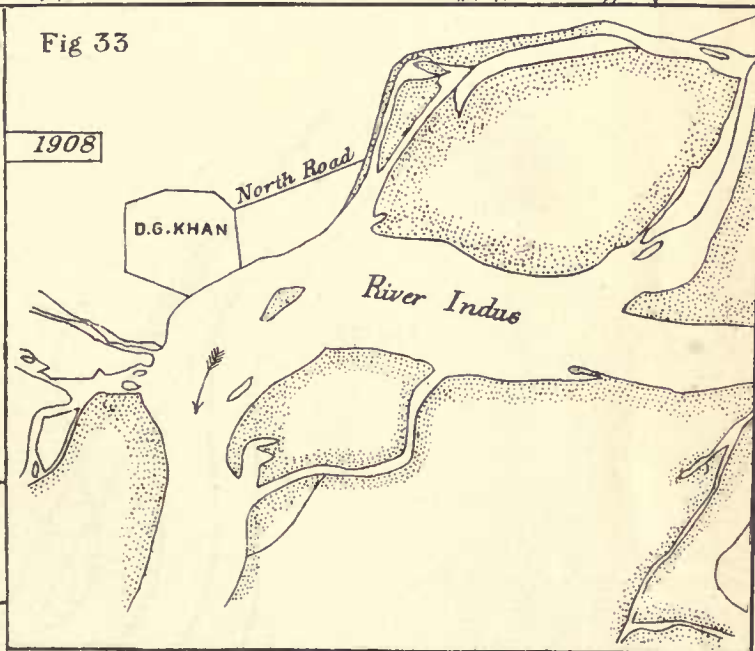


Fig. 30

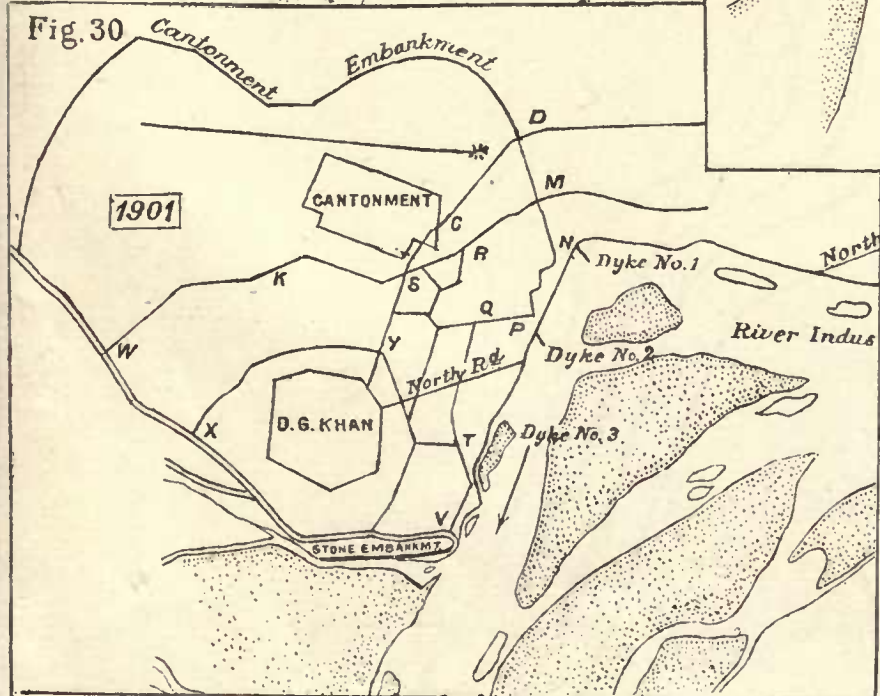


Fig. 34

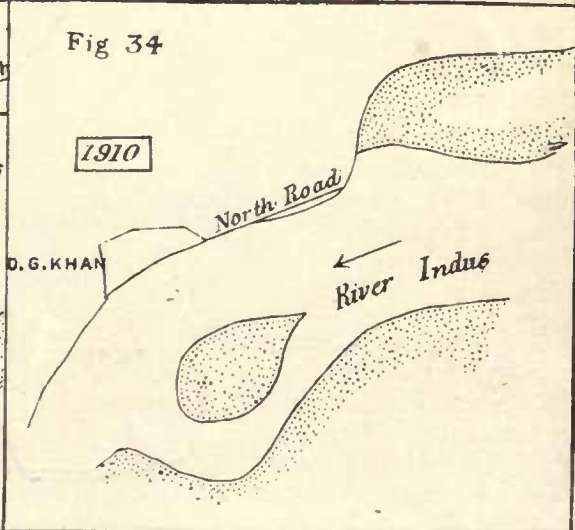


Fig. 41.

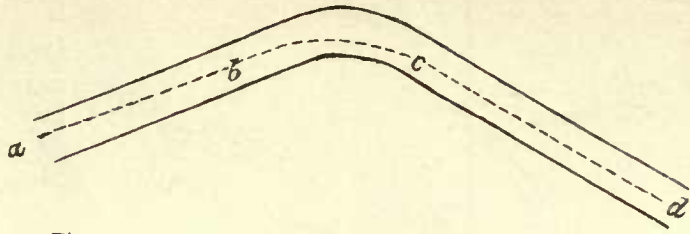


Fig. 42

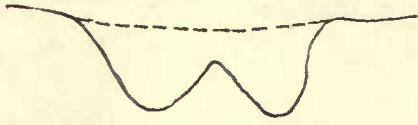


Fig. 43



Fig. 44

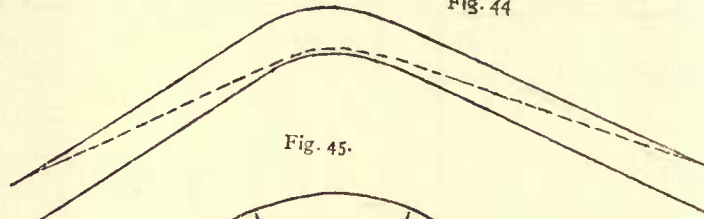


Fig. 45.

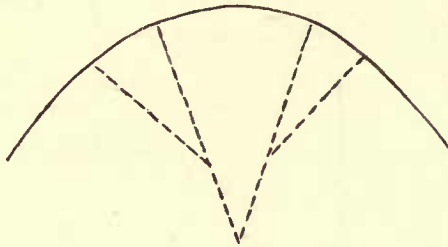


Fig. 46.

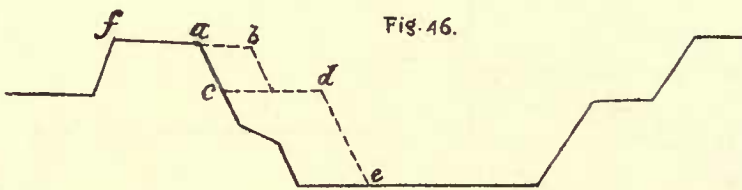


Fig. 39



Fig. 47

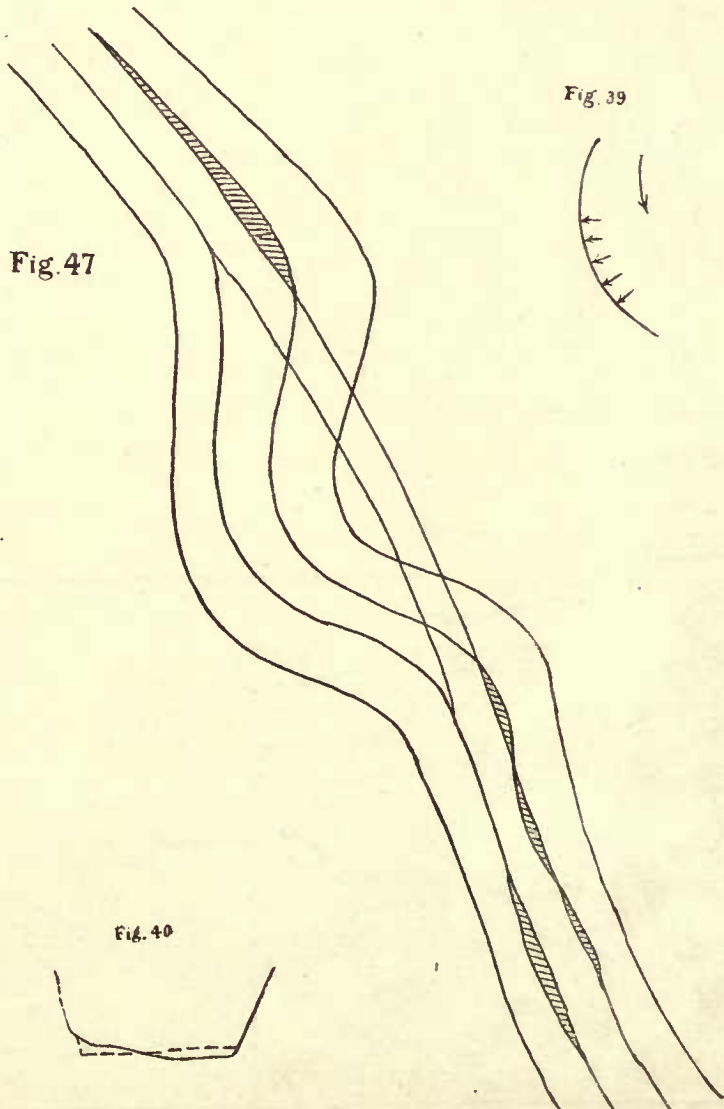


Fig. 40



RETURN

TO ➡

CIRCULATION DEPARTMENT

198 Main Stacks

LOAN PERIOD 1	2	3
HOME USE		
4	5	6

ALL BOOKS MAY BE RECALLED AFTER 7 DAYS

Renewals and Recharges may be made 4 days prior to the due date.
Books may be Renewed by calling 642-3405

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